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Report to the Bureau of Land Management

THE EXPERIMENTAL EFFECTS OF OFF-ROAD VEHICLE
SOUNDS ON THREE SPECIES OF DESERT VERTEBRATES

PART I: COUCH'S SPADEFOOT TOAD
(SCAPHIOPUS COUCHI)

PART II: MOHAVE FRINGE-TOED LIZARD
(UMA SCOPARIA)

PART III: DESERT KANGAROO RAT
(DIPODOMYS DESERTI)

by

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Final Report of

Contract CA-060-CT7-2737

CONTRACT SUMMARY

The Experimental Effects of Off-Road Vehicle Sounds on Three Species of Desert Vertebrates represents the final phase of a three-part study funded entirely by the Bureau of Land Management (CA-060-CT7-2737). The purposes of this study were to provide the BLM Desert Plan Staff with a comprehensive review of the existing literature concerning noise and its effects on vertebrates, baseline data describing ambient sound levels that occur in the deserts of California, and experimental data regarding the impact of ORV sounds on desert vertebrates. In compliance with these purposes the following reports were completed and submitted to the Riverside District Office of the BLM:

Part I: Bibliography on the Effect of Noise on Non-Human Vertebrates.

This report contains 2568 references concerning noise and its effects on vertebrates. The report is divided into three sections that contain non-federal, National Technical Information Service, and federal publications. The report is numerically cross-indexed by subject for easy access and retrieval of pertinent references. A supplement to this report, Guidelines for the Bureau of Land Management in the Use of the Bibliography on the Effect of Noise on Non-Human Vertebrates was developed to aid the BLM in the efficient use of the bibliography. Also included was a list of 95 articles of specific interest to the Desert Plan Staff. This supplement has since been incorporated as a foreword to the bibliography. These reports are now in press as a BLM technical publication.

Part II: Ambient Sound Pressure Levels in the California Desert.

This report contains baseline data from over 18 months of field sound surveys performed in the Mojave and Colorado Deserts of California. Also included are summaries of existing noise research of specific interest to the BLM. Descriptions and analyses of both natural and mechanized sounds and the effects of various ecological parameters on their attenuation are

also presented. Relative sound intensities and frequencies of occurrence of specific sounds are compared for several desert regions. An analyzed synthesis is presented which describes detailed information concerning ambient acoustical levels in the California Desert. Implications of these findings to the BLM are discussed. This report is also in press as a BLM technical publication.

Part III: The Experimental Effects of Off-Road Vehicle Sounds on Three Species of Desert Vertebrates (attached as the following pages) contains experimental data from three separate laboratory studies conducted to determine the impact of ORV sounds on desert vertebrates. Three classes of terrestrial desert vertebrates; amphibians, reptiles, and mammals were investigated with respect to sound impacts. Couch's Spadefoot Toads (Scaphiopus couchi), Mojave Fringe-Toed Lizards (Uma scoparia), and Desert Kangaroo Rats (Dipodomys deserti) all suffered deleterious effects from moderate exposures to ORV sounds. These effects included both physiological and behavioral hearing loss, and misinterpretation of important environmental acoustical signals. Potential impacts of ORV sounds on the well-being of natural populations of desert vertebrates are indicated and the implications of these findings to the BLM are discussed. Recommendations which seek to reduce the detrimental impacts of ORV's on habitats and wildlife of the California Desert are suggested. Each of these studies will also be submitted separately to scientific journals for publication, and several popular articles, based on these data, are also planned for separate publication.

Experiments to determine the effects of ORV sounds on captive desert birds were originally considered. These investigations, however, were not carried out after it became apparent, through the desert field surveys of Luckenbach (1978) and Weinstein (1978), that desert birds selectively avoided ORV areas and fled to less intensely used areas. Subsequent

conversations with M. Konishi and his staff at California Institute of Technology, likewise, suggested that it would be unlikely that free-ranging owls, which acoustically locate prey through the reception of faint high-frequency sounds, would remain in high sound level areas, if they had the opportunity to move into quieter areas. Further, the ability of continuous loud sounds (95-100 dB) to permanently damage the hearing of birds has already been demonstrated by Marler, Konishi, Lutjens and Waser (1973). It was for these reasons that our investigations were limited to determining the impacts of ORV sounds on members of those vertebrate classes that were incapable of successfully escaping from areas of high ORV use.

Luckenbach, R. A. 1978. An analysis of off-road vehicle use on desert avifaunas. Paper presented at 43rd N. Amer. Wildl. Conf. Phoenix, Ariz. 19 pp.

Marler, P., M. Konishi, A. Lutjen, and M. S. Waser. 1973. Effects of continuous noise on avian hearing and vocal development. Proc. Nat. Acad. Sci. USA. 70 (5): 1393-1396.

Weinstein, M. 1978. Man's impact on birds in Afton Canyon. Paper presented at California Desert Conservation Area Advisory Committee Meeting of November 30 - December 2. Riverside, California.

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The Effect of Motorcycle Sounds on the
Emergence of Couch's Spadefoot Toad, Scaphiopus couchi

by

Michael C. Bondello
Bayard H. Brattstrom

ABSTRACT

Twenty Scaphiopus couchi burrowed in 10 cm of fine sand within a 15 gallon terrarium were subjected to recorded motorcycle sounds of 95 dBA (100 dBL) for periods of 10, 20, and 30 minutes. Toads began to emerge from their shallow burrows shortly after the introduction of sounds. The numbers of toads that surfaced in response to the sounds were 1 - 7 ($\bar{x} = 3.3$) after 10 minutes, 4 - 11 ($\bar{x} = 5.7$) after 20 minutes, and 6 - 12 ($\bar{x} = 7.5$) after 30 minutes of sound exposure. A spectral analysis of motorcycle sounds is presented and correlated with the toads' ability to detect sounds.

The ecological implications of this behavior are discussed in terms of climatic considerations, and the consequences of misinterpreting critical acoustical stimuli are indicated. An appendix summarizing thunderstorm activity in the southwestern United States is affixed and the importance of thunderstorms to spadefoot toad ecology is implied.

The Effect of Motorcycle Sounds on the Behavior of the Common Frog (*Rana temporaria*)

by Michael C. Bondario and Robert H. Besterman

Michael C. Bondario
Robert H. Besterman

ABSTRACT

Twenty *Rana temporaria* tadpoles were exposed to 10 sec of recorded motorcycle sounds at 10, 20, and 30 dB (100 Hz) for periods of 10, 20, and 30 minutes. Tadpoles began to emerge from their shallow burrows shortly after the introduction of sounds. The number of tadpoles that emerged in response to the sounds were 1 - 7 ($\bar{x} = 3.3$) after 10 minutes, 4 - 11 ($\bar{x} = 6.7$) after 20 minutes, and 6 - 12 ($\bar{x} = 7.8$) after 30 minutes. A spectral analysis of motorcycle sounds is presented and correlated with the tadpoles' activity in detecting sounds.

EXPERIMENT I

The ecological significance of this behavior was discussed in terms of its adaptive value, and the consequences of misinterpreting critical acoustic stimuli are indicated. An appendix illustrating the sound activity in the common frog is included and the importance of understanding the significance of sound activity is implied.

INTRODUCTION

Off-Road Vehicle (ORV) activities in the California Desert have greatly increased in the past decade (Sheridan, 1979). Recent government reports (Webb and Wilshire, 1978) have documented the tremendous damage inflicted by ORV's on the geological and biological components of the California Desert Ecosystem. The potential threat of ORV sounds to the indigenous wildlife of formerly quiet, remote desert regions has also been suggested (Bondello and Brattstrom, 1978). More recently, laboratory studies have shown that sand dune inhabitants, Mojave Fringe-Toed Lizards, Uma scoparia, (Bondello, Huntley, Cohen, and Brattstrom, 1979), and Desert Kangaroo Rats, Dipodomys deserti, (Bondello, and Brattstrom, 1979), are particularly vulnerable to ORV sounds, with both species suffering serious hearing loss after moderate exposures of dune buggy sounds. The effects of ORV sounds on the inhabitants of peripheral areas near desert sand dunes has not been studied.

A relict population of Couch's Spadefoot Toad, Scaphiopus couchi, was reported by Mayhew (1965) to exist on the eastern periphery of the Imperial Sand Dunes, south of Glamis, Imperial County, California. This same region has received intensive ORV use in the past ten years. The impact of this intense ORV activity on this relict population of amphibians has not been determined.

Couch's Spadefoot Toad is a highly adapted semi-fossorial anuran that inhabits arid regions of the southwestern United States. The toad has a black, sickle-shaped "spade" on each hind foot that enables it to burrow to depths in excess of 50 cm beneath the desert surface. Within the burrow, the spadefoot is able to avoid the environmental extremes of the harsh desert surface for periods which may exceed one year (Mayhew, 1965).

Populations of S. couchi emerge from their burrows with the first summer thunderstorms (June-July) and aggregate at temporary pools of water where

mating occurs. Foraging may occur at some distance from these pools (McClanahan 1967). Their eggs may hatch within 48 hours and larvae mature within 10 days. Within three months, their weight may increase by 110% and length by 1100%. Metamorphosis is rapid and often completed before the temporary pools dry up (Mayhew, 1965).

After the seasonal summer thunderstorms have passed (September-October) the spadefoots dig into their burrows and remain buried until the next summer's storms (McClanahan, 1967). They do not emerge during winter rains, although similar pools may form (Mayhew, 1965). While buried in their burrows, S. couchi encounters physiological problems of food storage and water conservation (McClanahan, 1967).

S. couchi stores as much as 5% of its body weight as coelomic fat, with lesser concentrations in subcutaneous pectoral and pelvic regions. The coelomic fat can meet 94% of the energy requirements of a burrowed spadefoot at a temperature of 15° C for the entire sub-surface period (McClanahan, 1967). Burrow temperatures recorded in southeastern Arizona for S. hammondi fluctuated around 15° C ($\pm 10^\circ$ C) during the period of the spadefoot's subterranean existence (Ruibal et al, 1969). Storage and metabolism of coelomic fat, then, is the primary means by which S. couchi meets its energy demands while underground for extended periods (McClanahan, 1967).

Water conservation beneath the surface involves other spadefoot adaptations. Prior to digging into its burrow, S. couchi fully hydrates by absorbing water primarily through their integument. S. couchi can voluntarily store up to 30% of its standard body weight as dilute bladder urine. When dehydrated, this dilute urine can be used to replenish water lost from other body fluids. In addition to water storage abilities, S. couchi has high tolerances to water loss. Approximately 80% of a 25 gm S. couchi is water. S. couchi can lose over 40% of its standard body weight (60% of total body water) and still recover (McClanahan, 1967). Losses of only one-half of this

magnitude would be sufficient to kill most mammals (Schmidt-Nielsen, 1964). This high tolerance to water loss and rapid recovery when rehydrated facilitates the underground existence of S. couchi in arid regions.

S. couchi also has high tolerance to metabolic waste buildup. Urea, a nitrogenous waste, stored in the body fluids of burrowed spadefoots coupled with increased electrolyte concentrations, may actually double the plasma osmotic concentration of S. couchi (McClanahan, 1967). The increased osmotic concentration of the spadefoot's body fluids can facilitate the absorption of water from the soil (Ruibal et al; 1969). Thus, metabolic waste retention, increased concentration of body fluids, and permeability of the integument are all factors that contribute to the extended subterranean existence of S. couchi. Build up of dark, keratinized skin may also aid the conservation of water (McClanahan, 1967).

Aggregation and reproduction of populations of S. couchi in temporary pools formed by summer thunderstorms are facilitated by acoustical signals. Males have a vocal sac which produces both species-specific mating and release calls (McAlister, 1959).

The auditory system of S. couchi is quite different from that represented by other families of anurans. Most anurans have three distinct types of auditory nerve fibers with varying degrees of response which enable them to perceive sounds of lower, medium, and higher frequencies. S. couchi, however, has only two distinct types of auditory nerve fibers, one that responds to lower frequencies and one that responds to higher frequencies.

The lower frequency sensitive fibers have a range of sensitivity from 100 - 700 Hz with their best response at 480 Hz (54 dBL). These fibers probably derive from the amphibian papilla of the spadefoot's inner ear and exhibit tone-on-tone inhibition. The higher frequency sensitive fibers have a range of sensitivity from 900 - 1500 Hz with best response at 1400 Hz (64 dBL). These fibers probably derive from the basilar papilla of the spadefoot's inner ear and do not exhibit tone-on-tone inhibition. The

response properties of the higher-frequency sensitive group corresponds to the major spectral energies and temporal patterns of the spadefoot's mating (1300 - 2100 Hz) and release (1000 Hz) calls. The response properties of the lower-frequency sensitive group, however, do not correspond to spectral patterns of known biological significance. Thus, detection of predators and other environmental low frequency sounds has been suggested as the function of the fibers of the amphibian papilla (Capranica and Moffat, 1975).

The timing of the emergence of spadefoots during summer thunderstorms is of critical importance to the reproductive success of the population. Yet, the exact mechanism that initiates their emergence is not known. Prior to the rainy season on warm nights, spadefoots have been seen with only their eyes and snouts protruding from the surface (Bragg, 1965). Ruibal et al (1969) have eliminated rain as a necessary cue for emergence in that it was difficult to explain how a 1 mm rain could affect the soil environment at a depth of 30 cm. The exact environmental stimulus that is responsible for initiating the emergence of the spadefoots is, thus, not known.

It was, therefore, the purpose of this investigation to determine whether acoustical signals provide an environmental cue which could initiate the emergence of spadefoots. Specifically, we asked if, in the late Fall, in the absence of water, could mechanized sounds, with lower frequency energies trigger the emergence of a captive group of burrowed S. couchi? The results of these tests and spectral analysis of the mechanized sounds introduced are presented, and the ecological implications of the spadefoots' responses are discussed.

MATERIALS AND METHODS

Twenty S. couchi were obtained from the Arizona-Sonora Desert Museum in late Summer 1978 and allowed to acclimate in a 15 gallon terrarium filled with 10 cm of sand collected near Rice, California. The spadefoots were kept at an ambient air temperature of 22°C. The terrarium was placed on foam rubber pads 5 cm thick to insulate it from ground vibrations. An Electro-Voice SP8B 8-Inch Coaxial Loudspeaker was suspended 20 cm above the sand surface over the center of the terrarium. The speaker was connected to a McIntosh Model MI-75 Power Amplifier which amplified a recording of mechanized sounds from a TDK Endless 30 second loop tape, played back on a Panasonic Autostop cassette recorder. The mechanized recording consisted of sounds recorded from 30 massed 250 cc motorcycles. Spectral analysis of these sounds was performed with a Kay Electric Company Sound Spectrograph 6061B.

Seven experiments were performed with the spadefoots between 10 October and 20 November 1978. Experiments were conducted during early evening hours (1830-2130) and Controls always preceded Test runs. A bowl of fresh water was provided the spadefoots each week, but not until several days after each experimental session. Equal numbers of Control and Test runs were conducted at durations of 10, 20, and 30 minutes. Thus, a total of seven runs at 10 minutes, six runs at 20 minutes, and four runs at 30 minutes were conducted.

Test runs consisted of amplifying the motorcycle recording to an intensity of 95 dBA (100 dBL) monitored at the sand surface with a Bruel and Kjaer 2203 Sound Level Meter with condenser microphone and cable. The number of spadefoots on the surface was then visually observed and recorded at 5 minute intervals. If more than two spadefoots were on the surface prior to the experimental session, the experiment was terminated. Controls were conducted under similar conditions except no sounds were introduced.

Observations were initially made under red light, however, subsequent tests were performed under white light and, in one, instance, no light, with no apparent change in spadefoot behavior. Ear protectors were worn by the observer during the Test runs.

RESULTS

The number of spadefoots on the surface of the sand did not increase during Control runs, but did increase during the Test runs. The range of numbers for spadefoots on the surface was 0 - 2 ($\bar{x}$ = 0.8) for Controls. The numbers of toads on the surface during Test runs was 1 - 7 ($\bar{x}$ = 3.3) after 10 minutes, 4 - 11 ($\bar{x}$ = 5.7) after 20 minutes, and 6 - 12 ($\bar{x}$ = 7.5) after 30 minutes exposure to motorcycle sounds (Table I). Thus, motorcycle sound exposure resulted in the emergence of toads and the longer the duration, the more toads emerged (Fig. 1).

S. couchi exhibited quiescent behavior during Control runs. Toads on the surface rested in crouched positions with ventral surfaces held near, and often in contact with, the sand surface. Their eyes were loosely closed or half-opened, however, at times they opened widely as the toads peered out of the terrarium. Buccal pumping was slow and even at about one pump per second (1/sec). Burrowed spadefoots, visible through the glass walls, remained quite motionless with eyes tightly shut and limbs held closely to their bodies. Buccal pumping was very slow and not easily detected.

Spadefoot behavior changed when motorcycle sounds were introduced. Surface toads blinked and widely opened their eyes, slightly tensed, and raised their posture so that snouts were elevated about 30° from the substrate. Buccal pumping increased to about 2/sec as toads became more active. After several minutes, some toads slowly moved around the terrarium as others hopped quickly across the enclosure. Most toads, however, moved near the sides of the terrarium and remained there. Toads visible in shallow burrows shook slightly, gulped several times, and slowly unfolded limbs from their bodies while their eyes remained tightly closed. Then, they would slowly, but persistently, nudge their snouts into the soil above their heads and force their bodies upward. In a few minutes, they managed to dig through several centimeters of soil and break through several milli-

Table I Actual number and mean number of Scaphiopus couchi on surface of sand for Control and Exposed runs. Exposures equal 95 dBA (100 dBL) motorcycle sounds for durations of 10, 20, and 30 minutes.

<u>Date</u>	<u>Time (min)</u>	<u>Control</u>	<u>Exposed</u>
10 Oct 78	0	2	2
	10	2	6
	20	2	8
	30	2	12
23 Oct 78	0	1	1
	10	1	2
	20	1	5
	30	1	6
30 Oct 78	0	1	1
	10	1	4
	20	1	7
	30	1	7
6 Nov 78	0	2	2
	10	2	7
	20	2	11
	30	2	11
12 Nov 78	0	0	0
	10	0	1
	20	0	4
15 Nov 78	0	0	0
	10	0	2
	20	0	5
20 Nov 78	0	0	0
	10	0	7
Mean Numbers	0	0.8	0.8
	10	0.8	3.3
	20	0.8	5.7
	30	0.8	7.5

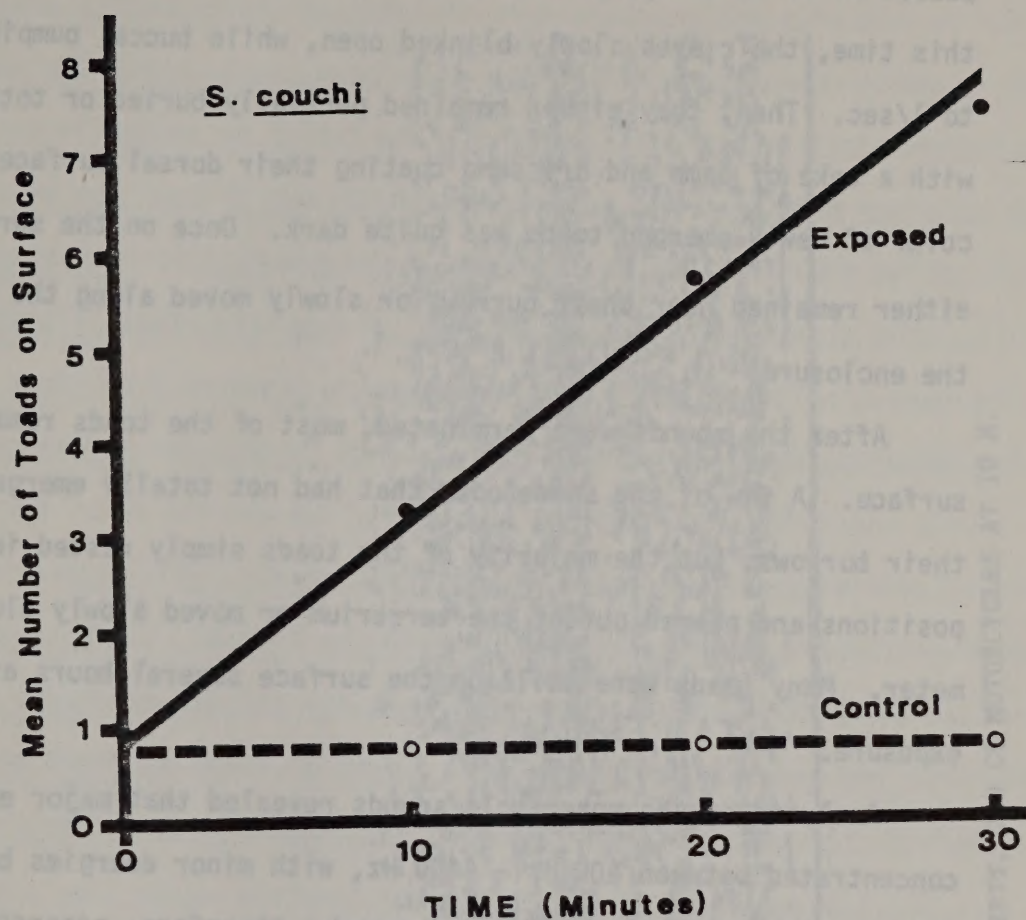


Figure 1: Mean numbers of spadefoot toads on surface during Control (open circles) and Exposed (closed circles) experimental runs. ($n = 7$ at 10 minutes, $n = 6$ at 20 minutes, and $n = 4$ at 30 minutes).

meters of compacted sand crust to arrive at the surface. The toads often paused prior to emerging, with only their snouts and eyes protruding. At this time, their eyes slowly blinked open, while buccal pumping increased to 1/sec. Then, they either remained partially buried or totally emerged, with a cake of damp and dry sand coating their dorsal surface. The skin color of newly emerged toads was quite dark. Once on the surface they either remained near their burrows or slowly moved along the perimeter of the enclosure.

After the sounds were terminated, most of the toads remained at the surface. A few of the spadefoots that had not totally emerged, dug back into their burrows, but the majority of the toads simply rested in stationary positions and peered out of the terrarium or moved slowly along the perimeter. Many toads were still on the surface several hours after sound exposure.

Analysis of the motorcycle sounds revealed that major energies were concentrated between 400 Hz - 4400 Hz, with minor energies between 250 - 7000 Hz (Fig. 2). The mechanized sounds, therefore, possessed major energies well within the range of the auditory nerve fibers of both the amphibian and basilar papillae of S. couchi (Capranica and Moffat, 1975).

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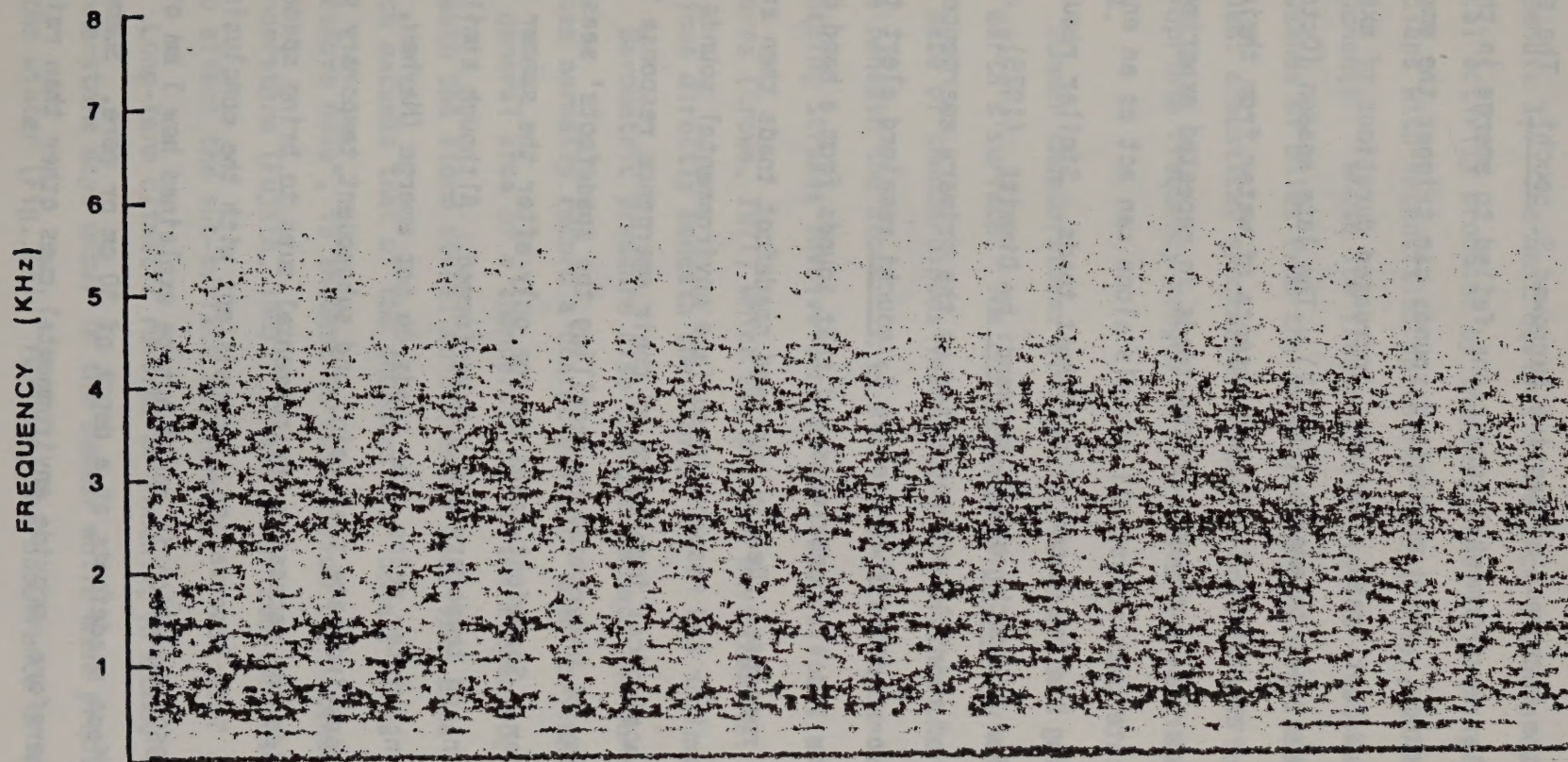


FIGURE 2: SONAGRAM OF THIRTY, 250 CC MOTORCYCLES AT 10 M.

DISCUSSION

Recorded motorcycle sounds of intermediate intensity have been shown to elicit the emergence of captive burrowed S. couchi. The same toads under similar environmental conditions failed to emerge in the absence of recorded sounds. Thus, mechanized sounds can trigger the emergence of captive spadefoot toads. Further, increased durations of exposure stimulated more toads to emerge (Fig. 1). The late season (October - November), presence or absence of light, and absence of water from their enclosure did not deter the emergence of the toads in repeated experiments. These data indicate that acoustical signals alone can act as an environmental cue in eliciting the emergence of spadefoot toads. Similar results have been reported for S. couchi and S. hammondi by Dimmitt (1975), wherein the sound of rainfall was suggested as the primary emergence cue. McClanahan (1967) also reported that captive S. couchi remained alert to sound while burrowed in leucite containers and that sounds from a hand drill initiated a digging response. Deeply burrowed spadefoot toads then are apparently able to monitor and respond to surface environmental sounds.

The ecological importance of their emergence response to acoustical stimuli may be understood by recalling the spadefoots' seasonal patterns of behavior. Spadefoot toads emerge only after the summer thunderstorms have begun and temporary pools have formed. Although similar pools may form during winter rains, the toads do not emerge (Mayhew, 1965). These observations indicate that rain, and subsequent temporary pools of water, do not provide the necessary environmental cues to bring spadefoots to the surface. This observation is consistent with the conclusions of Ruibal et al (1969) in which it could not be explained how 1 mm of surface rain could affect spadefoots at a depth of 30 cm or more. Summer thunderstorms must, therefore, provide environmental cues other than rain which may

account for the emergence of the spadefoots.

Summer thunderstorms are brief, intense, violent episodes of rainfall that differ in many respects from the "Mediterranean" rains of the winter (Appendix I). The most obvious difference is the greatly increased electrical activity produced by thunderstorms. Lightning strokes produce thunderclaps with intensities up to 120 dBA. (Miller, 1975) and with sound components whose low frequency signals (30 - 130 Hz) can be monitored thousands of miles from the thunderstorm (Holzer, 1955). The resultant violent acoustical shockwaves certainly contain sufficient energies in the appropriate frequency ranges to alert even the most deeply burrowed spadefoot.

Summer thunderstorms also produce severe local electrical changes at the earth's surface. The active separation of many negative charges at the base of thunderclouds induces a high positive charge at the earth's surface beneath the storm. This electrical activity and the resultant lightning strokes involve tens of millions of volts and thousands of amperes (Crowe, 1971) which may provide environmental cues to sub-surface regions directly beneath the storm.

Barometric pressure also changes beneath thunderstorms. Pressure traces normally record a characteristic "dome" of increased pressure under the general area of a thunderstorm. Often microbarographs located directly beneath the storm reveal an extremely localized area of high pressure which exceeds that of the thunderstorm "dome". This area, known as the "pressure nose", is thought to result from the intense downdraft of the thunderstorm (Fujita, 1963). These localized increases in pressure may also affect the sub-surface environment.

Long-term climatic records of Phoenix, Arizona, indicate that most thunderstorm days occur in the summer while most precipitation days occur in the winter (Fig. 3A). Further, the occurrence of thunderstorms in the

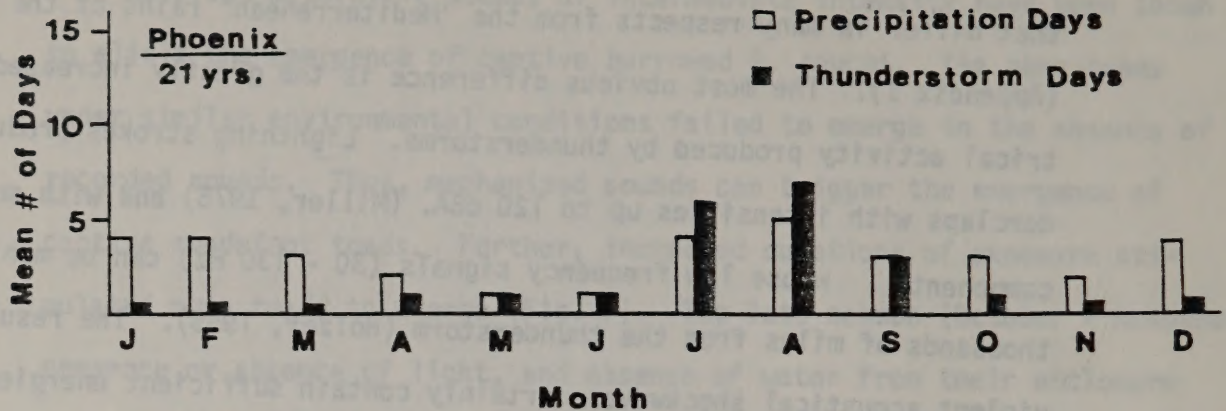


Figure 3 A: Comparison of mean monthly occurrence of days with precipitation over 0.25 mm (open boxes) and days with thunderstorms (closed boxes) for Phoenix, Arizona over a 21 year period.

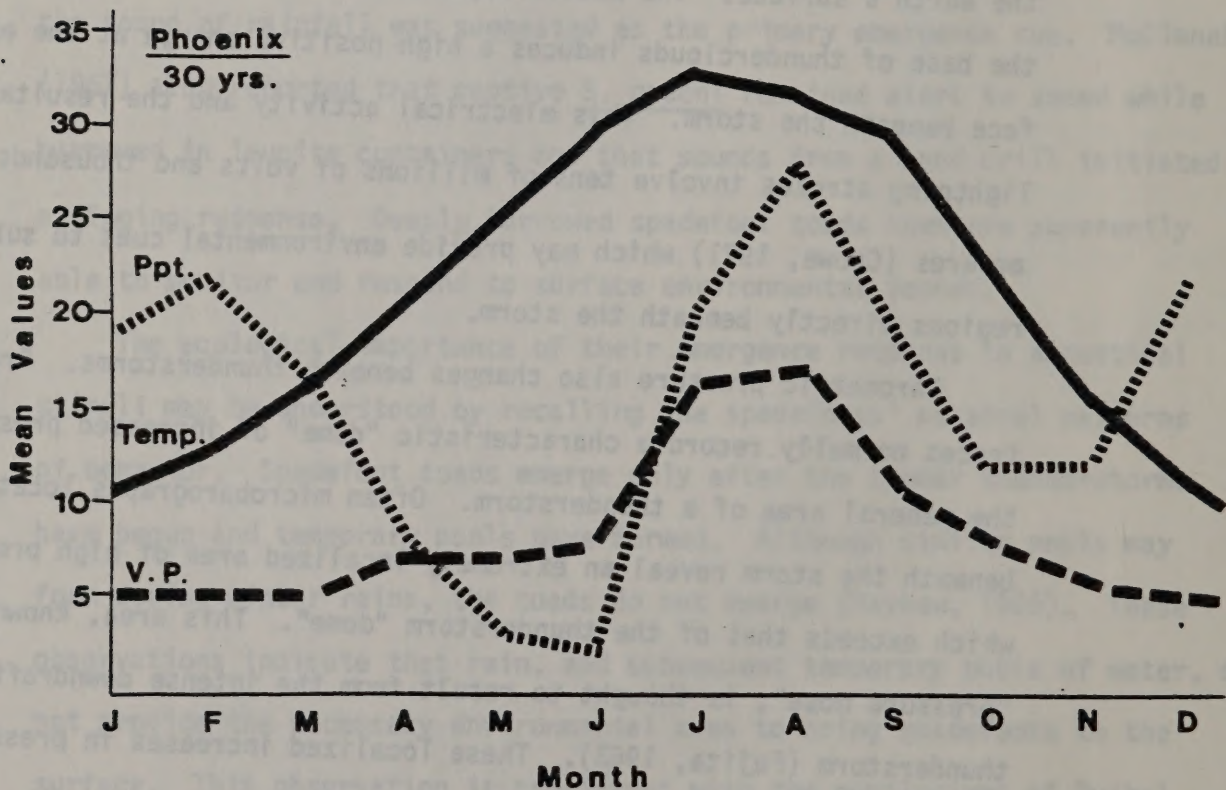


Figure 3 B: Comparison of mean monthly data of temperature ($^{\circ}\text{C}$)

summer coincides with mean annual maximum values of temperature and vapor pressure recorded for this region (Fig. 3B). Both temperature and vapor pressure increases may affect the sub-surface environment during the summer months.

Possible environmental cues, then, that may affect the sub-surface environment and alert the toads to the advent of summer showers include intense episodes of thunder and electrical activity, high barometric pressures, high temperatures and high vapor pressures. Brief, intense "cloudbursts" and formation of temporary pools may provide further environmental cues beneath the surface during the summer months.

Spadefoot toads that respond to the appropriate environment during the summer months have the advantages of temporary ponds for rehydration, courtship, and breeding purposes; adequate populations of larval and adult insect prey food and high temperatures for the rapid hatching and development of the young. Further, the rains may serve to dissolve the crust and loosen sub-surface soil sufficiently to facilitate their emergence.

The selective advantages of emerging during the summer when water, food, and temperatures are all at optimum levels are obvious. Thus, spadefoot toads have apparently evolved some kind of mechanism which coincides their annual emergence with the onset of summer showers. The same mechanism also precludes their emergence at inappropriate times of either inadequate water, food, or temperature.

Possible mechanisms which facilitate this behavior may include either adaptations of sensory abilities enabling the detection of specific environmental stimuli produced by summer thunderstorms or circadian rhythms enabling the synchronized emergence of spadefoots with the summer rains. These adaptations were presumably fixed in the spadefoot populations under natural conditions which were both spatially and temporally isolated from

human disturbance. Under natural conditions, the continued selective advantage of the emergence adaptation would be expected. Human disturbance however, is no longer spatially nor temporally isolated from spadefoot populations.

The impact of human disturbance on the fragile desert regions of the Southwest has been greatly intensified by the activities of ORV's. Impacts of ORV's on the desert environment include severe physical disruption of geological, floral, and faunal components (Webb and Wilshire, 1978). The ORV invasion has concomitantly spread high-intensity noise throughout formerly unexposed areas. ORV's generate the most frequently occurring high-intensity sounds that have been monitored in the California Desert (Bondello and Brattstrom, 1978). Experimental evidence indicates these sound intensities can produce hearing losses in the indigenous desert wildlife (Bondello and Brattstrom, 1979; Bondello, Huntley, Cohen, and Brattstrom, 1979).

The emergence of S. couchi in response to motorcycle sounds represents a potentially deleterious impact on the spadefoot populations. These toads were induced to emerge during the wrong season, in the absence of water and in the presence or absence of light. They were not reinforced with food or water, yet repeatedly emerged in subsequent sound exposures over several weeks. Thus, the spadefoots appear to be "locked in" to this response, without regard to critical environmental factors of water, food, or temperature.

The misinterpretation of acoustical cues by anurans has long been known. Florida Treefrogs normally emerge from seclusion in response to the increased humidities which occur prior to thunderstorms. Thunder can induce several frogs to emit "rain calls" simultaneously. However, airplane noises can elicit the same response from Hyla cinerea (Bogert, 196

Dimmitt (1975) reported the emergence of spadefoot toads in response to sounds generated by an off-balance electric motor in the absence of reinforcing environmental conditions. Thus, misinterpretation of acoustical information by anurans is not an uncommon occurrence.

ORV activities generate sounds with intensity and frequency characteristics sufficient to reach burrowed spadefoots. ORV sounds monitored at the periphery of the Imperial Sand Dunes near Glamis, California, ranged from 76 - 110 dBL over a 1 hour period in March, 1978. The ORV's were scattered over the dunes at various distances, however, most of the activities were concentrated on the periphery of the dunes. Individual or massed ORV's often generated high-intensity sounds for periods in excess of 5 minutes at any one spot (Bondello and Brattstrom, 1978). Both motorcycles (Fig. 2) and dunebuggies (Fig. 4) generate sounds with major energies concentrated in the lower frequencies. Thus, ORV's certainly generate sounds of sufficient intensity and frequency to be received and misinterpreted by nearby burrowed spadefoot toads.

The potential impact of ORV sounds on spadefoot populations near "ORV playgrounds" is tremendous. The Glamis-Imperial Sand Dunes represents one of these delicate areas. Mayhew (1965) reported isolated populations of S. couchi located on the periphery of the Algodones dunes 6 mi NW of Glamis, 2 mi SE of Glamis, and 7 mi SE of Glamis. The toads were apparently clustered along the eastern edge because the dunes act as a large dam in blocking run-off of rainfall from the Chocolate, Cargo Muchacho, and Picacho Mountains as the water flows toward the Salton Sea. The eastern periphery of the Algodones dunes, which contains these relict populations of spadefoot toads, therefore, comprise a particularly sensitive area to ORV's or any other equivalently loud mechanized activity (i.e. gunnery, mining, etc.). Such activities should, therefore, be restricted from this area.

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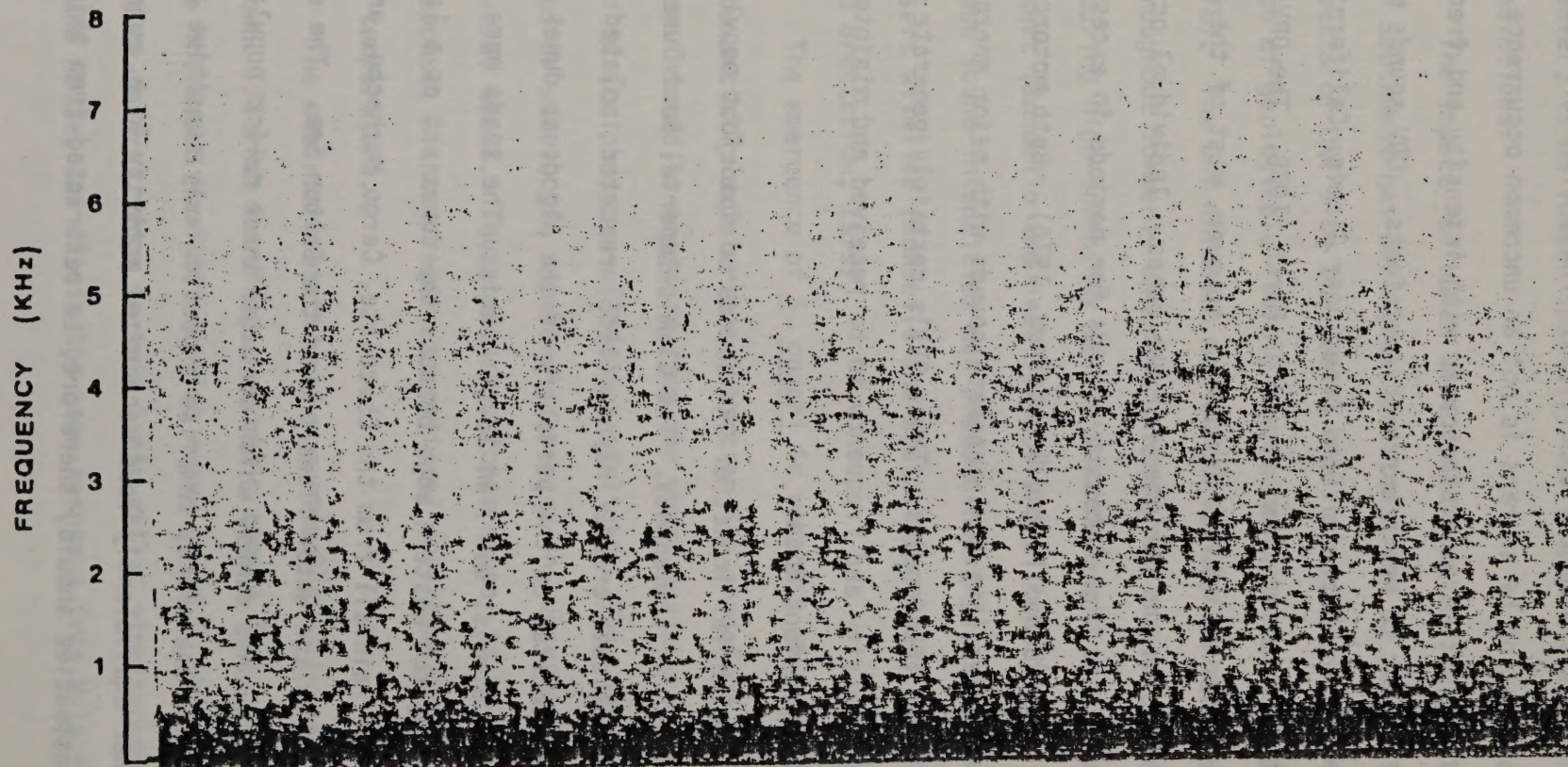


FIGURE 4: SONAGRAM OF 1971 VOLKSWAGEN BAJA BUG AT 5 M.

Unfortunately, the Algodones dunes near Glamis is widely known as "The Dune Buggy Capital of the World". ORV activities are prohibited only from the northern dune areas. Thus, the southern dunes are "open" to very intense ORV activity, particularly between March and June. The Glamis spadefoot population areas have, therefore, been subjected to high-intensity sound exposures in recent years. The current status of these relict populations is not known.

Recently emerged toads are severely stressed in that they are dehydrated and their fat reserves are depleted (McClanahan, 1967). The act of burrowing upward depletes energy reserves even more and dislodges keratinized layers of skin. Water and food must be available if the toads are to survive. If temperatures are not high enough, presence of appropriate insect prey and fat deposition may be affected and reproductive success would certainly be curtailed in that egg hatching and larval development would be slowed by the lower temperatures. Thus, if spadefoot toads were induced to emerge at any time other than the natural season of their emergence they would most certainly suffer deleterious effects.

The acoustically induced emergence of S. couchi has yet to be demonstrated under natural field conditions. Until appropriate field tests are conducted, laboratory evidence should be assumed to be correct and provisions made to protect known spadefoot populations from excessive mechanized sound exposure. Because all species of spadefoot toad emerge after summer thunderstorms, they should all be afforded this protection.

The emergence, survival, and reproduction of the spadefoot toad populations are timed to coincide exactly with favorable environmental conditions of water, food, and temperature. Their margin of error is slight and reproductive failures in spadefoot populations do occur (Bragg, 1946). These failures can be absorbed by the population if they are rare in

occurrence or do not affect the entire population. However, repeated losses of large numbers of adult and larval spadefoots, due to human disturbance, could not be long absorbed. The impact of mechanized sound on spadefoot populations may exceed their ability to tolerate such losses and severe reduction in numbers or localized extinction may potentially result.

CONCLUSION

Motorcycle sounds of 95 dBA (100 dBL) induced the emergence of burrowed Couch's spadefoot toads. Toads emerged shortly after the presentation of sounds and continued to emerge with increased duration of exposure. Inappropriate season, absence of water and high temperatures, and presence or absence of light did not deter the emergence of spadefoot toads. Spadefoot toad natural history, physiology, and behavior is briefly summarized.

Climatological data of the arid Southwest are included in Appendix I. These data reveal that summer thunderstorms provide different environmental stimuli than are normally associated with Mediterranean winter rains.

Climatic data suggests spadefoot toads are provided with varying types of environmental cues which "triggers" their emergence during the summer months, times of optimum water, food, and temperature. Interpretation of any or all of these climatic cues by spadefoots is proposed as the mechanism that results in their emergence response.

Implications of the misinterpretation of mechanized sounds by spadefoot populations are discussed, and potential impacts on relict populations of S. couchi near the Glamis-Imperial ORV playground are made. Protection of reported spadefoot populations along the eastern periphery of the Algodones dunes and restriction of excessive mechanized sounds from all known spadefoot population areas is advised.

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Appendix I

Climatological Conditions of the Southwestern United States

Rainfall occurs in two well-defined summer and winter rainy seasons in the southwestern United States (Dunbeir, 1968). Spadefoot toads, however, emerge only during the summer rainy season (Ruibal et al, 1969). This behavior may be more clearly understood by examining the contrasting climatic conditions that distinguish the two rainy seasons, particularly the differences between winter "Mediterranean" rains and summer thunderstorms.

Winter rains begin around November and continue, with interruptions, into March. These storms produce heavy "Mediterranean" type rains which cover large areas of the desert. They result from the southward movement of the Pacific subtropical high, which allows passage of low pressure areas into the desert regions. The majority of the annual rainfall received in the arid regions northwest of Tucson, Arizona, results from these mid-latitude cyclonic disturbances (Dunbeir, 1968).

Summer rains result from scattered thunderstorms which occur primarily in July, August, and September. Thunderstorms produce brief, intense cloudbursts which affect small areas of a few square miles. Summer thunderstorm activity is caused by the penetration of the North Atlantic subtropical anticyclone into Texas and northern Mexico. The arrival of moist tropical air from the Gulf of Mexico forces the North Pacific anticyclone to the North (Dunbeir, 1968).

Thunderstorm activity increases with the northwestern advance of Gulf tropical air (Dunbeir, 1968). In southern Arizona, between 1953-1962, the mean annual number of days with thunderstorms was highest (40 days/year) in the East and progressively decreased to the lowest incidence (10 days/year) in the West. The maximum frequency of occurrence of thunderstorms, between June-August, was 1400-1800 hours for this region (Bryson and Hare, 1974).

Thunderstorms form due to the general uplift and/or surface heating of unstable air masses (Bryson and Hare, 1974). Three stages of thunderstorm formation are recognized. These include the developing (cumulus) stage, maturing (active) stage, and dissipating (final) stage. The developing stage involves the ascent and supercooling of successive "bubbles" of warm air from the turbulent surface. This forms cumulus clouds which contain large quantities of liquid water. The maturing stage follows, wherein the release of large falling raindrops simultaneously create active downdrafts and accelerated updrafts. As the downdrafts strike the ground, they spread out and scoop up warm surface air into the tempest above. This self-sustaining active stage lasts 15-30 minutes and is characterized by intense rainfall and violent electrical displays. The final stage of dissipating clouds results when the updrafts cease and cloud temperatures equilibrate. Fine drops of light rain may fall for brief periods after the cessation of updrafts (Crowe, 1971).

The separation of positive ions to the top and negative ions to the bottom of thunderclouds, induces a positive charge at the earth's surface. A lightning stroke produces an avalanche of free ions between the oppositely charged cloud base and the earth's surface. Lightning strokes may travel well over a mile, involve tens of millions of volts, reach a maximum of 20,000 amperes and raise the air temperature of its narrow path to $15,000^{\circ}\text{C}$. Thunder results as a shockwave produced by this explosive expansion (Crowe, 1971).

Thunderstorms can not be individually identified, but are catalogued by the number of "days with thunder heard" (Bryson and Hare, 1974). Long term records of southwestern weather stations indicate a characteristic seasonal pattern of thunderstorm day occurrence. Santa Fe, New Mexico, between 1904-1943, reported 80.5% of mean thunderstorm days between June-September (Byers and Braham, 1949). The majority of mean annual thunderstorm days reported for Phoenix, Arizona (77.2%), were between June-September over a 21 year period. Summer precipitation, however, represented less than half

of the mean annual days of precipitation reported for Phoenix (38.2%) over a 30 year period (Bryson and Hare, 1974). Long term records, therefore, indicate most of the days of thunderstorm activity in the southwest above Tucson, occur in the summer, while more days of precipitation occur in the winter (Fig. 3A).

Long term records also indicate seasonal patterns of variation for mean annual precipitation, temperatures, and vapor pressures for the southwest. Summer rainfall, while intense, represented only a minority (37.5%) of the mean annual rainfall reported for Phoenix over a 30 year period. Mean temperatures and vapor pressures also attained maximum values in the summer months during the same period (Bryson and Hare, 1974). Thus, between June-September, the southwestern United States above Tucson receives less than one half of its annual rainfall in brief intense periods of high thunderstorm activity. The summer season is further characterized by periods of high mean values of temperature and vapor pressure (Fig. 3B).

Analysis of southwestern climatic conditions therefore indicates that the known time and season of emergence of spadefoot toads (June-September) is well-correlated with periods of most intense thunderstorm activity and the highest temperature and vapor pressures. Summer thunderstorm activity and associated climatic phenomena also provides a variety of environmental stimuli, which may alert the burrowed spadefoots of the arrival of favorable surface conditions.

The Effects of Bone Density on the Electrophysiological Auditory
Responses of the Guinea Pig
Abstract
The effects of bone density on the electrophysiological auditory responses of the guinea pig were studied. The results show that bone density has a significant effect on the auditory response. The response was measured by the amplitude of the auditory evoked potential (AEP). The AEP was recorded from the auditory cortex of the guinea pig. The results show that the AEP amplitude was significantly higher in the high bone density group than in the low bone density group. This suggests that bone density has a significant effect on the auditory response. The results also show that the AEP amplitude was significantly higher in the high bone density group than in the low bone density group. This suggests that bone density has a significant effect on the auditory response. The results also show that the AEP amplitude was significantly higher in the high bone density group than in the low bone density group. This suggests that bone density has a significant effect on the auditory response.

EXPERIMENT II

The results of Experiment II show that the AEP amplitude was significantly higher in the high bone density group than in the low bone density group. This suggests that bone density has a significant effect on the auditory response. The results also show that the AEP amplitude was significantly higher in the high bone density group than in the low bone density group. This suggests that bone density has a significant effect on the auditory response. The results also show that the AEP amplitude was significantly higher in the high bone density group than in the low bone density group. This suggests that bone density has a significant effect on the auditory response.

The Effects of Dune Buggy Sounds on the Telencephalic Auditory
Evoked Response in the Mojave Fringe-Toed Lizard, Uma scoparia

by

Michael C. Bondello
Anthony C. Huntley
Harry B. Cohen
Bayard H. Brattstrom

ABSTRACT

Eight Uma scoparia were surgically implanted in their telencephalic auditory regions with active silver electrodes in order to monitor their auditory evoked responses to stimuli of known intensities before and after exposure to dune buggy sounds (95 dBA, 100 dBL). Averaged evoked responses (AER) determined by computer-averaging their telencephalic electroencephalogram (EEG) were compared to determine effects of sound exposure.

Decreased amplitudes and increased latencies of AER resulted after sound exposures of 500 seconds. These data are interpreted as denoting actual hearing loss in test animals. The importance of the hearing sense to desert prey animals, relative vulnerability of their hearing apparatus, and critical reproductive cycles of populations of Uma within California are discussed with reference to the ecological significance of these findings.

INTRODUCTION

The invasion of the Southern California deserts by off-road vehicles (ORV's) has resulted in the spread of high-intensity sounds into formerly quiet, remote arid regions. Individual ORV's with sound intensities as high as 110 dBL have been monitored at several desert locations. Massed ORV activities generating high-intensity sounds have been recorded for durations in excess of five minutes. ORV sounds have been found to permeate deep into the desert and raise the ambient sound levels at distances exceeding 1 km (Bondello and Brattstrom, 1978).

Animals exposed to high-intensity sounds have suffered both anatomical and physiological damage. These effects include both auditory and non-auditory damage. Most noise research, however, has been conducted on animals from non-desert habitats (USEPA, 1971) and only recently have the effects of ORV sounds been investigated (Bondello, 1976).

High-intensity sounds of massed off-road motorcycles were shown to severely damage the acoustical sensitivity of the Desert Iguana, Dipsosaurus dorsalis. Exposures of 115 dBA for durations of one and ten hours both resulted in decreased cochlear responses to acoustic stimuli (Bondello, 1976). The Dipsosaurus study demonstrated that high-intensity ORV sounds can damage the peripheral auditory system of desert lizards. "Hearing", as measured by the changes in the electrical activity of the central nervous system (CNS) in response to acoustical stimuli, was not monitored in the Desert Iguanas.

Transient changes in the electrical activity of the CNS in response to sound have long been observed in the electroencephalogram (EEG) of human and non-human vertebrates. The background EEG is often of greater magnitude than those transient changes elicited by acoustic stimuli. The observation of these smaller transient changes in EEG has been greatly facilitated by the use of computer

averaging techniques, which electronically add the EEG signals. This technique allows the presumably random, larger background electrical activity to factor itself out through successive additions, while the smaller, non-random, time-locked responses, elicited by the acoustical stimuli, grow into recognizable patterns (Goldstein, 1973). These average evoked responses (AER) have been used for years as clinical criteria in the evaluation of hearing for both human and non-human subjects (Davis, 1976). The measurement of AER's of non-human subjects traditionally involves the placement of intracranial electrodes, in contrast to the extracranial placements normally made on human subjects (Keidel, 1976).

AER's have been monitored from a number of non-human vertebrates including; dogs, cats, rabbits, guinea pigs (Chaloupka, 1966), monkeys (Clopton, 1973), rats (Clopton and Winefield, 1974), bats (Suga, 1964; Grinell, 1970; Andreeva, 1976), porpoises (Bullock and Ridgway, 1972), sea lions (Bullock, Ridgway, and Suga, 1971), dove (Viederman-Thorson, 1967), snakes (Hartline, 1971), lizards (Campbell, 1969), and bullfrogs (Frishkopf and Capranica, 1966). Thus, AER's have been successfully used to determine hearing thresholds in mammalian, avian, reptilian, and amphibian subjects for over a decade.

AER's have been determined for several species of lizards native to the California deserts including; the Desert Banded Gecko, Coleonyx variegatus variegatus (Gekkonidae), the Western Whiptail Lizard, Cnemidophorus tigris (Teiidae), the Yellow-Backed Spiny Lizard, Sceloporus magister uniformis (Iguanidae), the Desert Iguana, Dipsosaurus dorsalis (Iguanidae), the Coachella Valley Fringe-Toed Lizard, Uma inornata (Iguanidae), and the Mojave Fringe-Toed Lizard, Uma scoparia (Iguanidae). Poor AER's were obtained from Dipsosaurus dorsalis and Uma scoparia, thus, these lizards were considered incapable of hearing low intensity sounds (Campbell, 1969). More recent experiments by

Werner (1972) have contradicted Campbell's results and have shown both Dipsosaurus dorsalis and Uma scoparia to be quite sensitive to low intensity sounds as determined by cochlear response. Campbell's inability to obtain proper AER's probably resulted because the lizards were tested during a season when their hearing responses were at a naturally-occurring low ebb. Seasonality of hearing sensitivity has been observed in other lizards. Inner ear responses of the Australian Stumpy-Tailed Skink, Trachysaurus rugosus, fluctuated with the season, and were ten times higher during the Spring than the Fall season of Australia (Johnstone and Johnstone, 1969).

The purpose of this study was to determine the hearing thresholds of the Mojave Fringe-Toed Lizard, Uma scoparia, using the AER technique. The AER's were to be recorded during the appropriate Summer season to insure a proper intensity of response. Following the recording of a control AER, an individual lizard was to be removed and subjected to a moderate duration (8 minutes and 30 seconds) of dune buggy sounds of intermediate intensity (95 dBA). Following the sound exposure, the AER of the lizard would again be recorded, to allow comparison with the control response. In this way, the actual effect of the dune buggy sound on the individual lizard's hearing threshold could be determined.

These dune buggy sounds represent lower intensities and shorter durations than the maximum reported field values, and have been used to make the study more relevant to exposures more likely to be received by lizards in the field. Uma scoparia was selected because the species range is restricted to aolian sand dune areas only, thus making it a likely recipient of dune buggy sounds as they occur in the field. Because of their limited species range, successful emigration to quieter neighboring habitats by Uma scoparia is not possible.. The lizards used in this study were obtained in an undisturbed dune area five kilometers south of Rice, Riverside County, California.

MATERIALS AND METHODS

Twenty Uma scoparia were captured by noosing, 5 km south of Rice, Riverside County, California, on 9 July 1978. Lizards were placed into an acoustically-insulated plastic container with internal dimensions of 66 cm x 30 cm x 30 cm. Subjects were immediately transported to California State University, Fullerton, Orange County, California. Animals were randomly separated into two separate acoustically-insulated plastic containers with internal dimensions as above. The insulated boxes could reduce a 100 dBA external noise by 35 dBA. Ten lizards were stored in each box on a substrate of sand taken from their home dunes. An electric timer, connected to a ten-watt light bulb placed on the sandy surface of each container maintained a 12 hour light, 12 hour dark cycle. A Yellow Springs Instrument Company Model 44TD Telethermometer with four thermister probes monitored the internal temperature of each container. Temperatures within the boxes ranged from 22°C in darkness to 39°C in light. Temperature decreased with distance from the light bulb, which established a thermal gradient in each container. A Schultheiss Quick-Recording Thermometer was used to periodically check the cloacal temperatures of individual lizards. These checks showed the lizards to maintain their temperatures near the preferred 35.7°C reported by Brattstrom (1965). Lizards were maintained on a daily diet of Tenebrio larvae and water. Compartments were cleaned daily.

Lizards were anaesthetized with Sodium pentobarbital (Abbott Labs) injected intraperitoneally at a dosage of 30-40 mg/kg body weight. The subjects were ready for surgery within 25 minutes of injection.

Eight animals were used, seven for testing and one for mapping the electrical responses of the brain. Anaesthetized lizards were secured, dorsum up, in a stereotaxic device, placed inside a grounded copper Faraday cage, located

within an acoustically-insulated room. The head was tightly secured, with care taken to avoid crushing the delicate skull. Surgery was performed to remove the parietal, postorbital and nasal scales. Two 1/32 inch holes were drilled in the skull using a dental drill. The first hole, in the nasal bone, was filled with a #80 stainless steel machine screw, 1/16 inch in length. A silver wire, wrapped on this screw, served as an indifferent recording electrode. The second hole, in the parietal bone, 2 mm caudal to the parietal eye and 0.5 mm to the right of midline, allowed passage of the active recording electrode. This electrode was made of 30 guage silver wire covered by glass drawn to within 1 mm of its tip. Careful inspection of each electrode for cracks and breaks was made. Finally, a silver wire ground was passed through the base of the tail. The electrodes were routed, via silver wire in copper coaxial cable, to a Grass Model 7 Polygraph, equipped with a J3b preamplifier and 7 DAF driver amplifier. Output from the driver amplifier (jack J6) was recorded on a Vetter frequency modulated magnetic tape system onto BASF tape at a speed of 7½.

The active electrode was slowly lowered into the lizard's telencephalon while the EEG of the animal was closely monitored on a Tektronix Model 5113 Dual Beam Storage Oscilloscope. A click stimulus with a rise time of less than 2 usec and fall time of 5 usec was presented using a Grass Model SD9 stimulator wired directly to a small hearing aid-type earphone placed against the tympanic membrane of the right ear. A series of 100 msec pulses were delivered at a rate of 10 pulses/sec. A 10 msec prepulse output from the SD9 was used to trigger the oscilloscope. The pulse was viewed on a separate channel of the oscilloscope. Both prepulse and pulse were recorded on the Vetter tape system. The active electrode was then lowered further until the characteristic "N-shaped" evoked response was observed on the oscilloscope.

The active electrode was then cemented into place using dental cement and allowed to dry. The experimenter was thus able to view the instantaneous time-locked response on the oscilloscope, with the potential for later analysis of the magnetic tape. A Computer of Average Transients (CAT 400B) was used to average 500 responses for each subject at stimulus intensities, read from the SD9, of 0.1 V (76 dBL), 0.2 V (80 dBL), 1.0 V (83 dBL), and 2.0 V (85 dBL). A total of three recordings of each stimulus intensity were made for each animal, two prior to and one directly after, exposure to dune buggy sounds. After the tape had been checked for play-back quality, the CAT 400B record was transcribed onto paper via a Beckman 10" Chart Recorder run at a chart speed of 5 inches/min and a pen deflection of 22.2 cm/20 μ V. The first negative peak of the response (1N) was then measured from the chart record to determine the magnitude of the AER before and after sound exposure.

Lizards were maintained at a body temperature of $38^{\circ}\text{C} \pm 1^{\circ}\text{C}$ during each test run by covering them with a warm water jacket. Head temperatures varied from cloacal temperatures by less than 1.8°C as determined by thermister placement. These temperatures are similar to those reported by Werner (1972) in obtaining smooth acoustical sensitivity functions from Uma scoparia.

Preliminary experiments were conducted from 12 July to 10 August 1978. The actual measurement of AER for the seven test lizards occurred on 11 August 1978. A lizard was surgically implanted and soon after, the first series of stimuli was presented. After this test, the lizard was disconnected from the stereotaxic apparatus and removed, with electrode still implanted, to a quiet room for a period of 30 to 90 minutes. The lizard was then reinserted into the apparatus and the electrode reconnected. A second run was then made to determine any effect due to the process of disconnection and removal from the apparatus. After the second run, the lizard was again

disconnected and removed to an insulated chamber. Here the lizard was exposed to a total of 500 seconds of taped dune buggy sounds (95 dBA, 100 dBL). The subject was then reconnected to the apparatus and immediately tested for the third time. Thus, a total of 21 runs were made (three runs per lizard), 14 before noise exposure and 7 directly afterwards. After the third run, lizards were removed, sacrificed, and prepared for histological examination.

High intensity sounds of a 1971 Volkswagen "Baja Bug" were recorded onto a TDK Endless 30-second loop tape, using a battery-powered Panasonic Autostop Cassette Recorder with condenser microphone. A simultaneous recording was made using a Uher 4000C portable tape recorder, for later sonograph analysis. The duration of the dune buggy sound was 25 seconds for every 30 second loop of the tape. Thus, for the 30 second loop tape, the sounds were "on" for 25 seconds and "off" for 5 seconds. The noise exposure then, was interrupted and not continuous. Twenty revolutions of the tape were played which resulted in a total sound exposure of 500 seconds (8 minutes and 30 seconds). A Kay Electric Company Sound Spectrograph set on "normal" analyzed the relative intensity distribution of the sounds over the frequency spectrum. A Bruel and Kjaer Precision Sound Level Meter Type 2203 with 1613 Octave Band Filter Set monitored the overall intensity of the dune buggy sounds.

The dune buggy sounds were played to the lizards from the loop tape, via the cassette recorder, to a McIntosh Model MI-75 Power Amplifier which amplified the signal through to an Electro-Voice SP8B 8-inch Coaxial Loudspeaker. Signal intensity was increased until 95 dBA (100 dBL) was reached 8 cm in front of the speaker. This intensity is lower than the maximum (105 dBL) value actually recorded from dune buggies in the field (Bondello and Brattstrom, 1978).

RESULTS

The intensities of the 1971 Volkswagen "Baja Bug" recorded in this study exceeded 95 dBA (100 dBL) at 5 meters. Sonograph analysis (Figure 1) revealed major energies concentrated below 1000 Hz with minor energies extending to 2500 Hz and residual energies up to 8000 Hz.

The typical response to a 0.1 msec pulse of 0.1 V (76 dBL) is given for the first control run of lizard #20 (Figure 2). The response is characterized by alternating negative (upward) and positive (downward) deflections. The first negative (1N) peak occurs at 1.5 msec after the termination of the stimulus. This 1N peak is followed by the first positive (1P) peak at 2.5 msec, the second negative (2N) peak at 3.5 msec, and the second positive (2P) peak at 5.5 msec after the stimulus. The waveform then steadily rose to regain the normal baseline EEG pattern until the next stimulus was presented.

The amplitude of the control 1N peak varied with the stimulus intensity (Table 1). Control 1N peak amplitudes ranged from 0.9-3.1 μ V ($\bar{X}$ = 1.67) for stimulus intensities of 0.1 V (76 dBL), 1.1-5.3 μ V ($\bar{X}$ = 2.63) at 0.2 V (80 dBL), 1.8-9.8 μ V ($\bar{X}$ = 5.59) at 1.0 V (83 dBL), and 1.8-10.5 μ V ($\bar{X}$ = 5.70) at 2.0 V (85 dBL). Increased stimulus intensities, then, tended to increase the amplitude of the 1N in the control runs up to intensities of 2.0 V (85 dBL) (Figure 3).

Preliminary tests performed on the lizard used to electrophysiologically "map" the AER revealed that the amplitude of the 1N peak did not vary as a linear function of intensity (Figure 4). The magnitude of the 1N AER of the "map" lizard rose to a maximum at 1.0 V (83 dBL) and steadily fell to lower values with increased stimulus intensities of 2.0 V (85 dBL), 4.0 V (86 dBL), and 6.0 V (87 dBL). This non-linear function after the maximum 1N peak is consistent with the findings of Werner (1972) and probably represents the

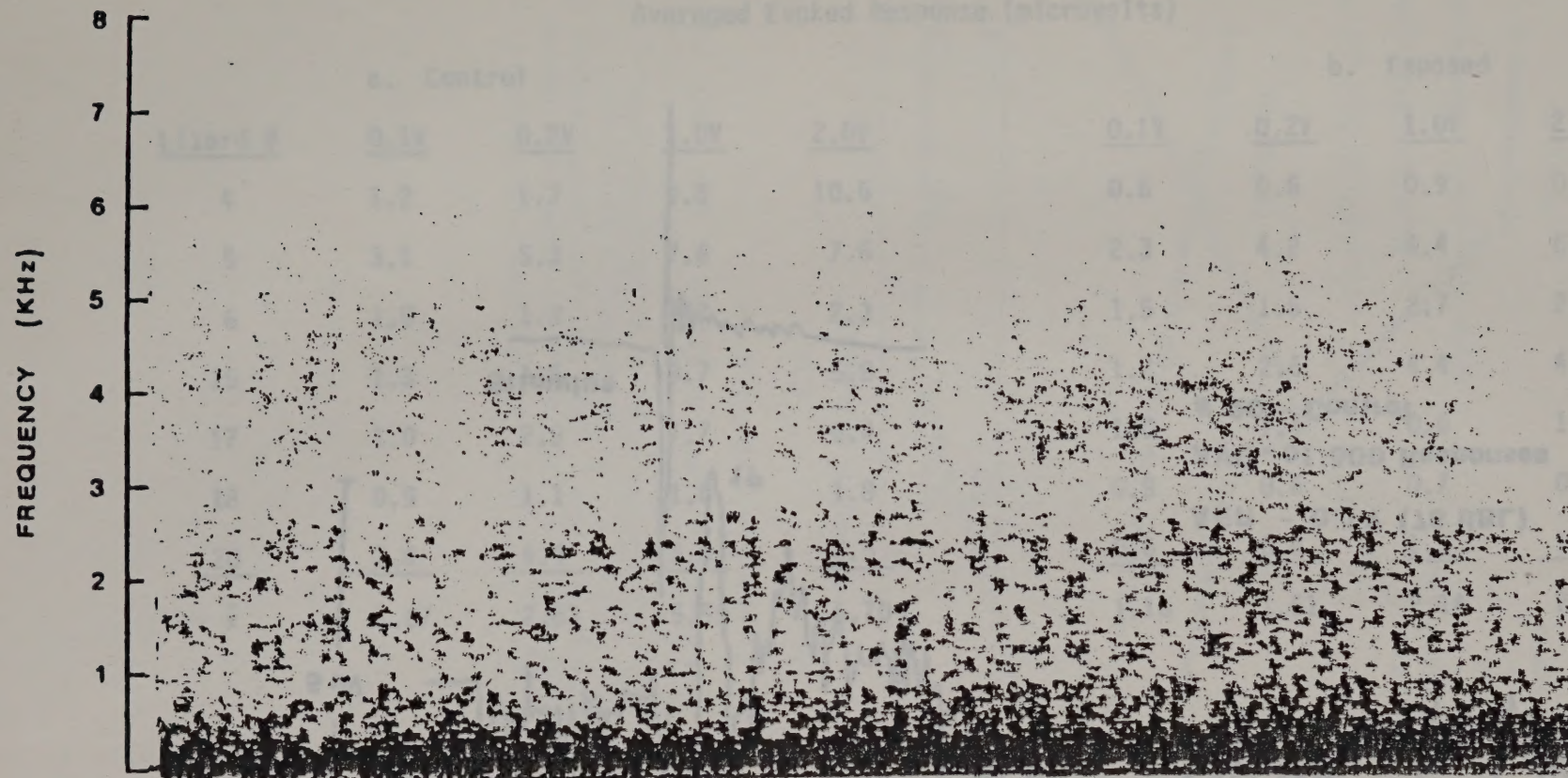


FIGURE 1: SONAGRAM OF 1971 VOLKSWAGEN BAJA BUG AT 5 M.

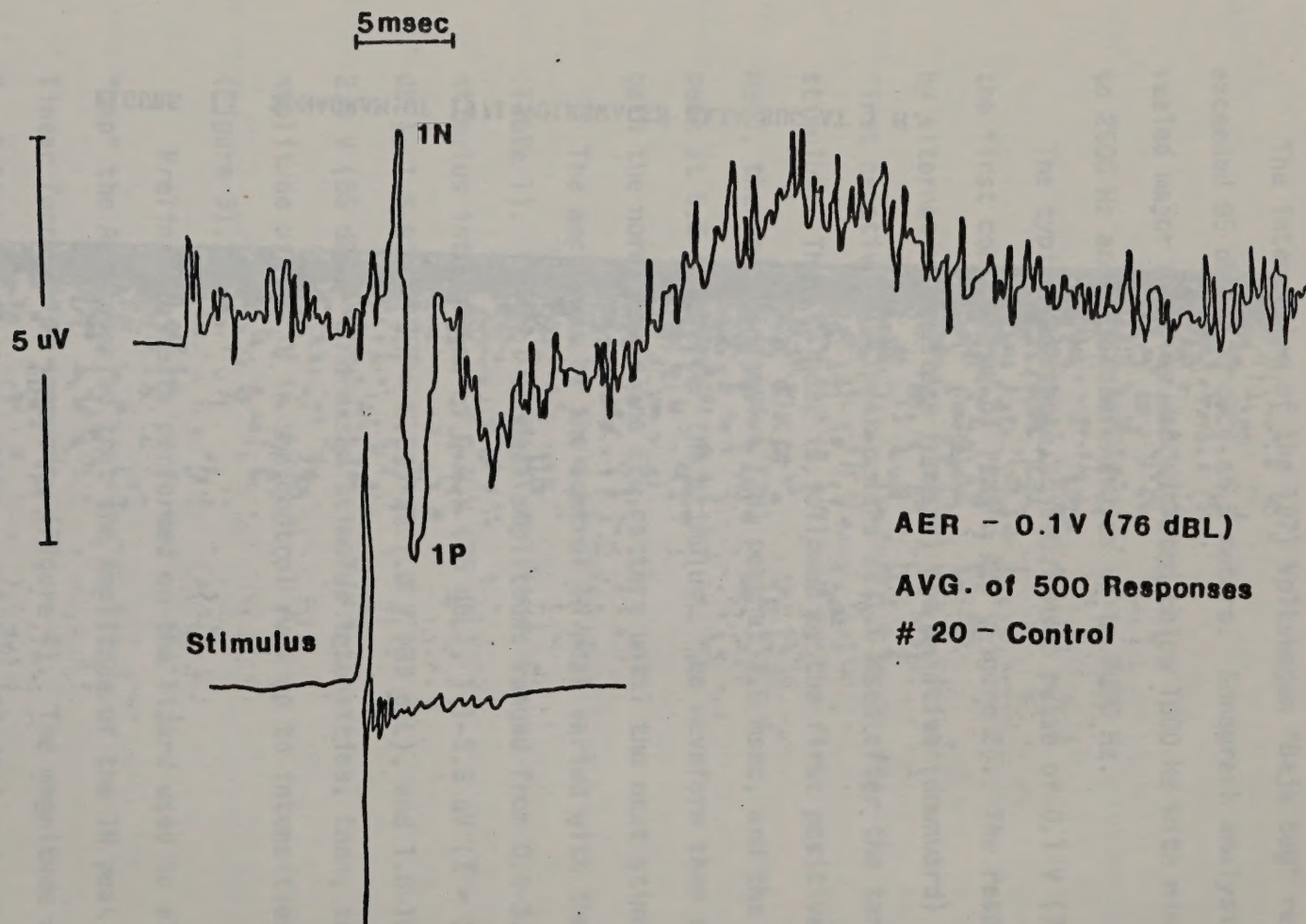


Figure 2: Average evoked response (AER) of lizard #20 to a stimulus of 0.1 V (76 dBL) during a Control run. First negative (1N) response occurs at 1.5 msec after the stimulus, the first positive (1P) response occurs at 2.5 msec. 500 responses were averaged to produce this waveform.

Table I Amplitude of the first negative (1N) average evoked response (AER) in microvolts of the Control and Exposed runs for 7 *Uma scoparia* at four stimulus intensities of 0.1 V (76 dBL), 0.2 V (80 dBL), 1.0 V (83 dBL), and 2.0 V (85 dBL). 500 responses were averaged for each intensity.

Averaged Evoked Response (microvolts)								
a. Control					b. Exposed			
Lizard #	<u>0.1V</u>	<u>0.2V</u>	<u>1.0V</u>	<u>2.0V</u>	<u>0.1V</u>	<u>0.2V</u>	<u>1.0V</u>	<u>2.0V</u>
4	1.2	1.3	9.8	10.5	0.6	0.6	0.9	0.6
5	3.1	5.3	7.6	7.6	2.3	4.2	4.4	6.5
6	1.8	1.8	2.7	2.3	1.5	1.5	2.7	2.0
15	1.3	1.6	3.7	5.8	1.2	2.6	4.4	4.0
17	1.0	2.9	7.7	6.4	1.0	1.4	0.6	1.7
18	0.9	1.1	1.8	1.8	0.9	0.6	0.7	0.8
<u>20</u>	<u>2.4</u>	<u>4.4</u>	<u>5.8</u>	<u>5.5</u>	<u>0.6</u>	<u>0.4</u>	<u>1.3</u>	<u>1.8</u>
$\bar{x}$	1.67	2.63	5.59	5.70	1.16	1.61	2.14	2.49

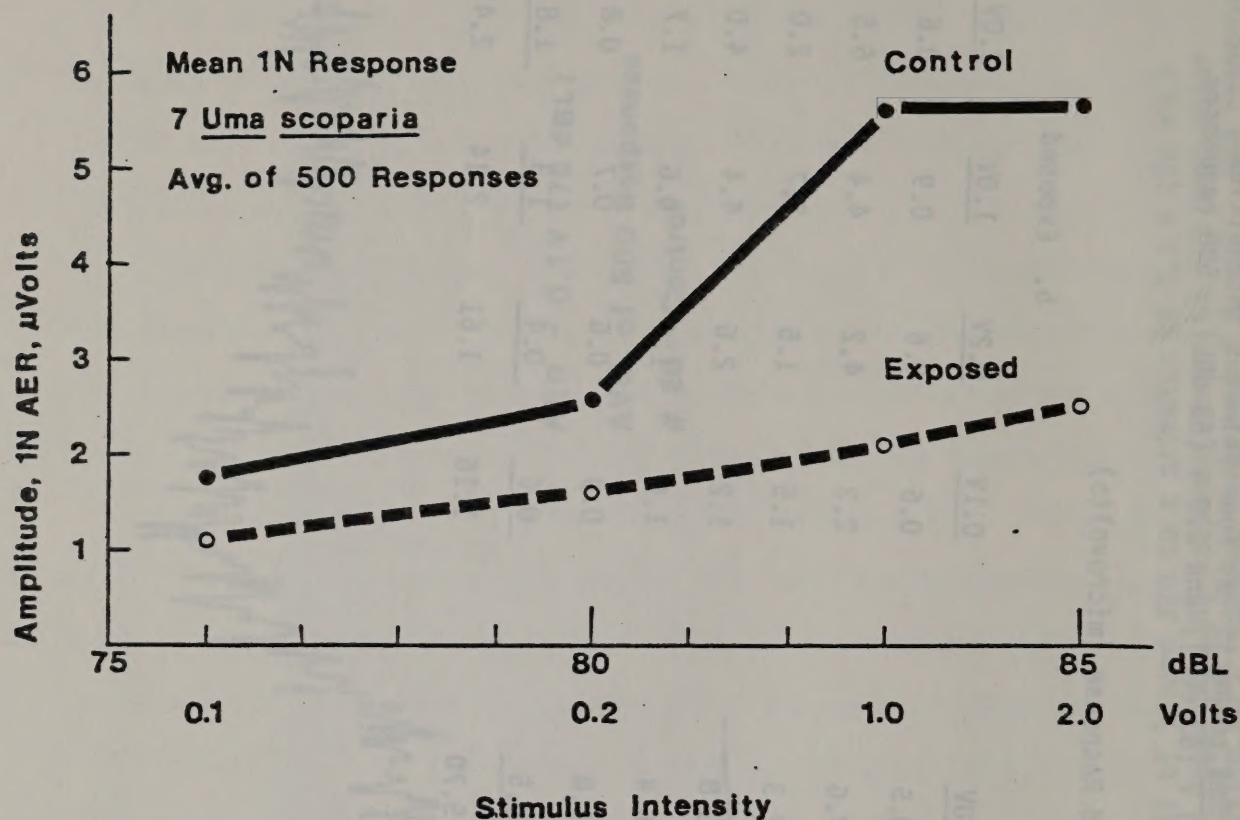


Figure 3: Comparison of the mean amplitude of the first negative (1N) average evoked response (AER) in microvolts (μ Volts) for the Control and Exposed runs of 7 Uma scoparia at four stimulus intensities of 0.1 V (76 dBL), 0.2 V (80 dBL), 1.0 V (83 dBL), and 2.0 V (85 dBL). 500 responses were averaged for each subject at each intensity. (solid line = Control, dashed line = Exposed).

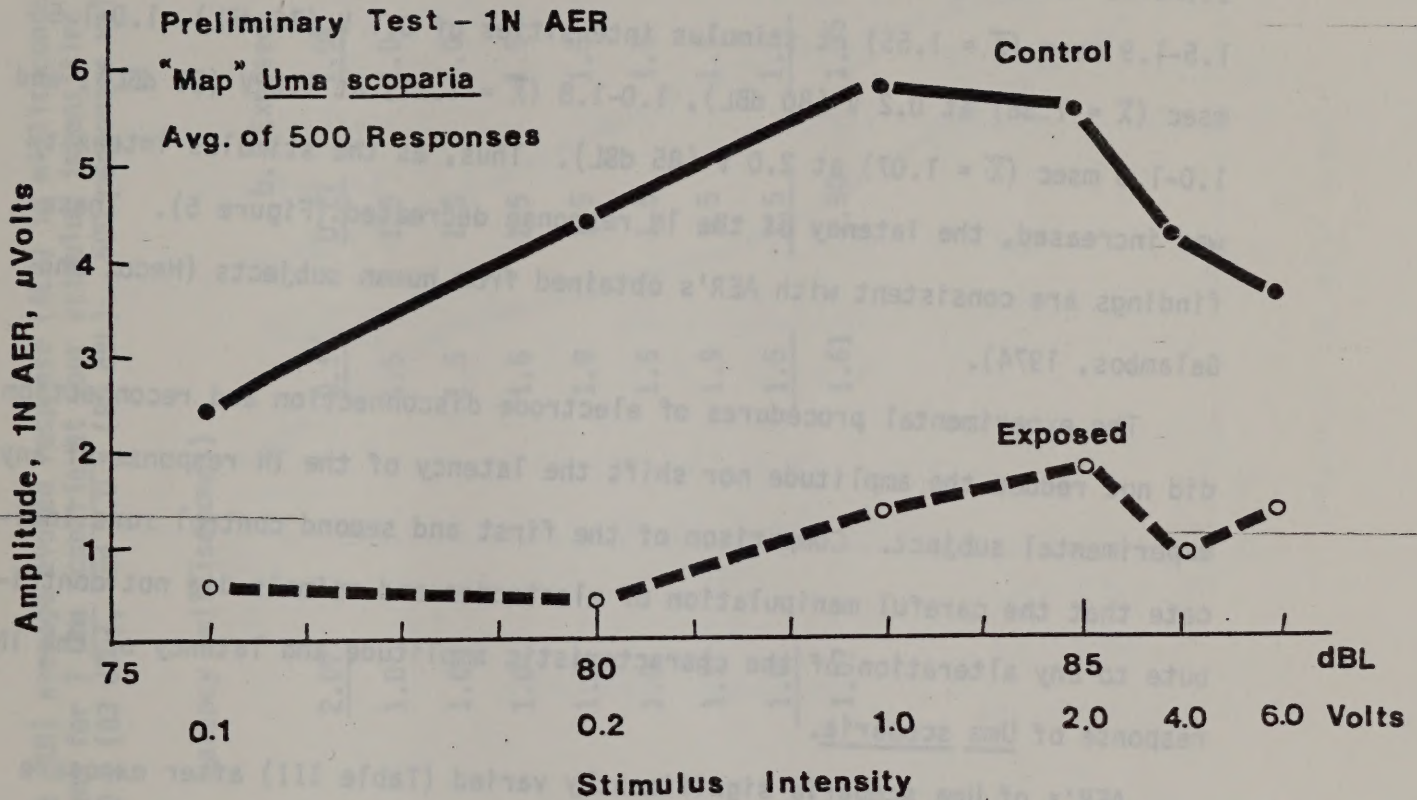


Figure 4: Preliminary test of the lizard used to electrophysiologically "map" the first negative (1N) average evoked response (AER) for Control and Exposed runs at six stimulus intensities of 0.1 V (76 dBL), 0.2 V (80 dBL), 1.0 V (83 dBL), 2.0 V (85 dBL), 4.0 V (86 dBL), and 6.0 V (87 dBL). 500 responses averaged at each intensity. (solid line = Control, dashed line = Exposed).

point at which the increased acoustical input overloads the ability of the sensitive lizard ear to respond.

The latencies of the 1N peak following stimulation also varied with stimulus intensity (Table II). The 1N peaks of the first control run were 1.5-1.9 msec ($\bar{X} = 1.55$) at stimulus intensities of 0.1 V (76 dBL), 1.0-1.5 msec ($\bar{X} = 1.38$) at 0.2 V (80 dBL), 1.0-1.8 ($\bar{X} = 1.21$) at 1.0 V (83 dBL), and 1.0-1.5 msec ($\bar{X} = 1.07$) at 2.0 V (85 dBL). Thus, as the stimulus intensity was increased, the latency of the 1N response decreased (Figure 5). These findings are consistent with AER's obtained from human subjects (Hecox and Galambos, 1974).

The experimental procedures of electrode disconnection and reconnection did not reduce the amplitude nor shift the latency of the 1N response of any experimental subject. Comparison of the first and second control runs indicate that the careful manipulation of electrodes and animals did not contribute to any alteration of the characteristic amplitude and latency of the 1N response of Uma scoparia.

AER's of Uma scoparia significantly varied (Table III) after exposure to dune buggy sounds (Figure 6). Comparison of first control runs with exposed (after sound treatment) runs showed the amplitude of the mean 1N responses to decrease (Table I a and b) and latencies to increase (Table II a and b) after exposure to dune buggy sounds. Decreased amplitudes and increased latencies of neural responses to standard auditory stimuli are diagnostic symptoms of hearing loss as described by Aran (1971). The decreased amplitudes (Figure 3) and increased latencies (Figure 5) caused by the dune buggy sounds are, therefore, interpreted as representing actual hearing losses in the exposed lizards. Seven Uma scoparia, therefore, suffered actual hearing loss after being exposed to 500 seconds of 95 dBA (100 dBL) dune buggy sounds.

Table II Latency of the first negative (1N) average evoked response (AER) in milliseconds (msec) of the Control and Exposed runs for 7 *Uma scoparia* at four stimulus intensities of 0.1V (76 dBL), 0.2 V (80 dBL), 1.0 V (83 dBL), and 2.0 V (85 dBL). 500 responses were averaged for each intensity.

Lizard #	Latency (milliseconds)							
	a. Control				b. Exposed			
	<u>0.1V</u>	<u>0.2V</u>	<u>1.0V</u>	<u>2.0V</u>	<u>0.1V</u>	<u>0.2V</u>	<u>1.0V</u>	<u>2.0V</u>
4	1.5	1.2	1.0	1.0	1.5	1.5	1.0	1.0
5	1.5	1.3	1.2	1.0	1.5	1.5	1.0	1.0
6	1.5	1.0	1.0	1.0	1.5	1.5	1.5	1.5
15	1.5	1.5	1.5	1.0	1.9	1.5	1.5	1.5
17	1.5	1.5	1.5	1.0	1.5	1.5	1.5	1.5
18	1.9	1.5	1.8	1.5	1.9	1.5	1.5	1.0
<u>20</u>	<u>1.5</u>	<u>1.5</u>	<u>1.0</u>	<u>1.0</u>	<u>1.5</u>	<u>1.5</u>	<u>1.5</u>	<u>1.5</u>
$\bar{x}$	1.55	1.38	1.21	1.07	1.61	1.50	1.35	1.28

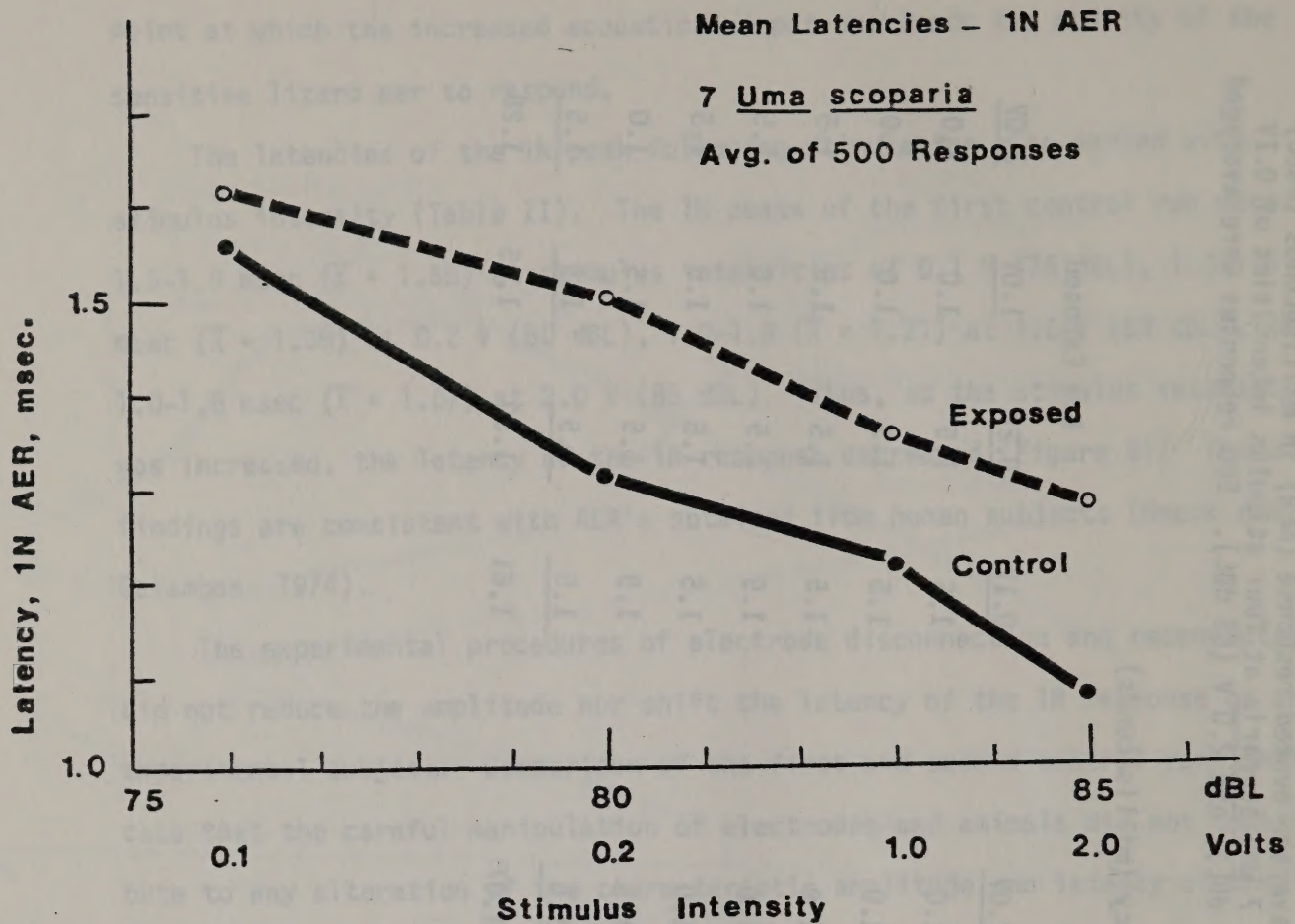


Figure 5: Effects of click intensity on the mean latency in milliseconds (msec) of the first negative (1N) average evoked response (AER) for the Control and Exposed runs of 7 Uma scoparia at four intensities of 0.1 V (76 dBL), 0.2 V (80 dBL), 1.0 V (83 dBL), and 2.0 V (85 dBL). 500 responses averaged for each subject at each intensity. (solid line = Control, dashed line = Exposed).

Table III Two-way ANOVA with replication for 7 Uma scoparia tested on 11 August 1978.

Source of Variation		df	SS	MS	F _s
	Sub.	7	154.4613	22.066	
A	Exp. Gp.	1	58.6302	58.6302	15.342 ***
B	Treat.	3	72.2877	24.096	6.305 **
Interaction					
	A x B	3	23.5434	7.848	2.054 ns
	Error	48	183.4286	3.821	
	Total	55	337.8899		

F .001 (1.40) = 12.6

F .01 (3.40) = 4.31

ns P $\geq$ 0.5

** P $\leq$ 0.05

*** P $\leq$ 0.01

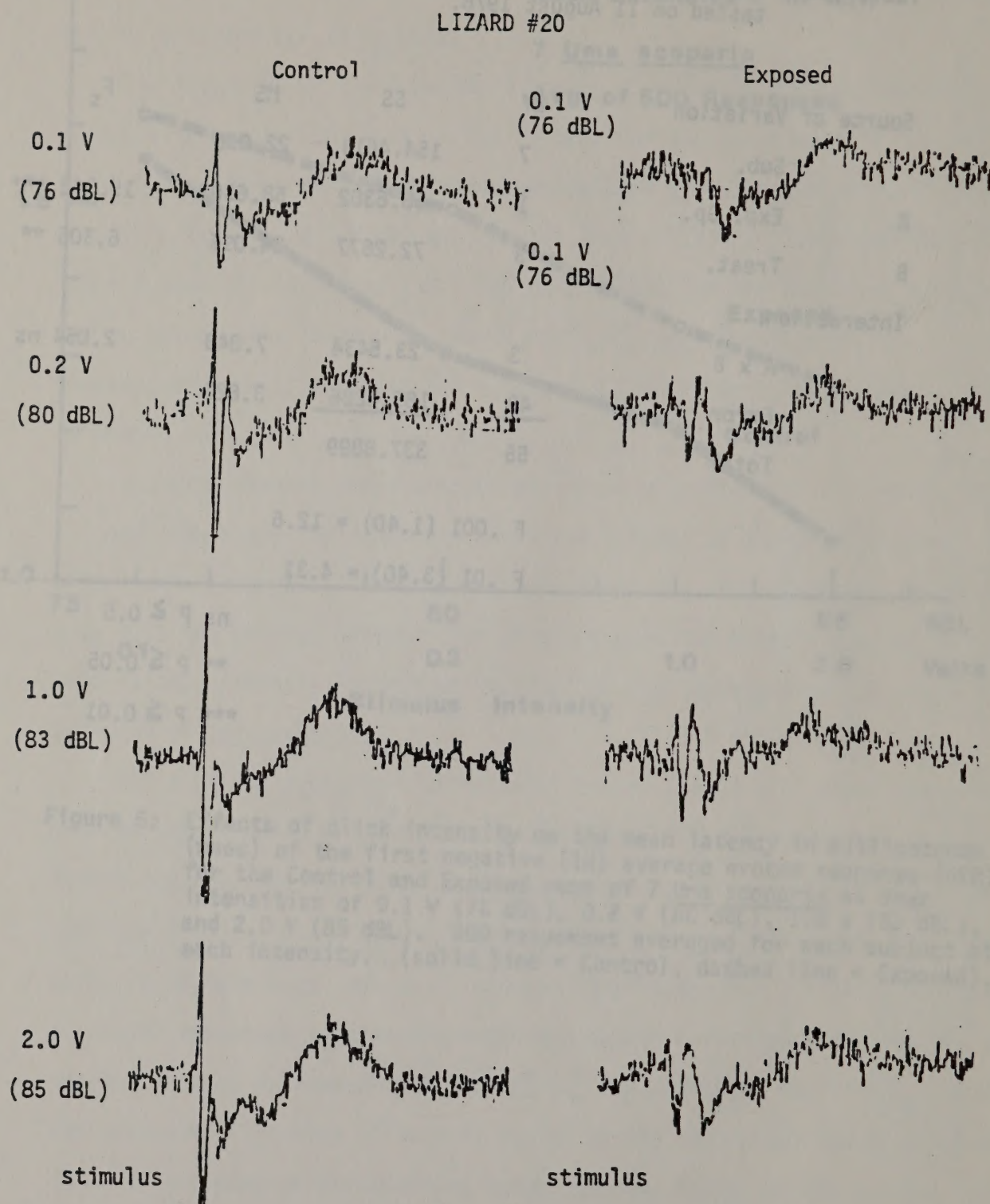


Figure 6: Comparison of the average evoked response (AER) of lizard #20 for Control and Exposed runs at four stimulus intensities of 0.1 V (76 dBL), 0.2 V (80 dBL), 1.0 V (83 dBL), and 2.0 V (85 dBL). 500 responses averaged for each intensity. Note the decline in the amplitude and increase of the latency of each response as a result of the exposure to dune buggy sounds.

Histological examination revealed the locations of the electrode implants. These exact locations correspond to the right medial (auditory) zone of the anterior dorsal ventricular ridge of the right telencephalic hemisphere as described for Iguanids by Northcutt (1978). Thus, the electrodes were implanted in the proper neuroanatomical coordinates to record auditory evoked potentials.

DISCUSSION

These data clearly indicate that dune buggy sounds of comparatively moderate intensity and short duration contain sufficient acoustical energies below 3 KHz (Figure 1) to induce hearing loss in Uma scoparia, as evidenced by decreased amplitudes (Figure 3) and increased latencies (Figure 5) of the first negative responses of their AER. Mechanized sounds of equivalent or larger acoustical dosage may, therefore, be expected to inflict similar detectable hearing losses on Uma scoparia exposed during the spring and summer seasons.

The early electrophysiological responses monitored from the lizard telencephalon are similar to those recorded from the brain stem of human subjects. (Hecox and Galambos, 1974). The sequence of negative and positive waves which appear before the first 10 msec after stimulation were originally described by Jewett, Romano, and Williston (1970) as being surprisingly consistent in occurrence with an absence of electrical artifact beyond the first fraction of a millisecond. The reliability of these early responses has been demonstrated as a useful method of assessing hearing in infant and adult human subjects, some of whom were incapable of voluntarily responding to auditory stimuli (Hecox and Galambos, 1974). The same procedures are, therefore, regarded as an accurate method of evaluating the hearing thresholds of similarly non-communicative lizards.

The earliest AER in human subjects, Jewett and Williston's peak I, appears about 1 msec post-stimulus and presumably results from the first neural volley of the auditory nerve (Hecox and Galambos, 1974). The 1N response of Uma scoparia (1-1.5 msec), then, is assumed to reflect a similar firing of the lizard auditory nerve. The designation "1N" is not meant to imply any relation to the early peak "I" (Jewett et al, 1970) or the later "n₁" responses of previous workers (Davis, 1976). Rather, 1N is used only to designate the first negative waveform of the AER of Uma scoparia described in this study and should not be confused with any other clearly defined nomenclature assigned to other recognized response waves.

A brief explanation is required to place this laboratory study within a framework of ecological relevance. This explanation concerns the nature and occurrence of dune buggy sounds and the activities of the fringe-toed lizards themselves.

The most frequently occurring, high-intensity sounds monitored in the Southern California Desert over an 18-month survey were generated by ORV's. Individual ORV's have been monitored with SPL's as high as 110 dBL (Bondello and Brattstrom, 1978). Formerly remote quiet desert areas are now traversed regularly by ORV's. Massed ORV activities can raise the ambient SPL's for durations of several hours. The most frequently encountered ORV's in the California deserts were motorcycles (Bondello and Brattstrom, 1978), however, most motorcycles are unable to penetrate the interiors of the wide soft sand dune systems characteristic of the Imperial Sand Dunes, Devil's Playground, and the Rice Sand Hills. Dune areas, then, are often spared the intense motorcycle activities, which tend to be concentrated in less difficult terrain (hardpan, sandy washes, and dune peripheries). Sand dune systems, then, represent a greater challenge to ORV enthusiasts due to their relatively more difficult terrain. The result is that four-wheeled vehicle activity (jeeps, sand rails, Baja bugs, etc.) tends to be most intensely concentrated on the sand dunes. Dune buggies are able to penetrate deep into the interior of sand dune systems due to their superior maneuverability and traction on the sandy substrate. Many areas within the dune periphery are, therefore, exposed to repeated episodes of high-intensity sounds. Dune buggies most often maximize engine speeds in order to maneuver over or through soft sand areas. Accelerated engine speeds produce similar elevations of sound pressure levels, thus, high-intensity sounds are often characteristic of dune buggy activities.

Dune buggy sounds with major energies concentrated below 3 KHz (Figure 1) have been monitored with intensities of 105 dBL at ranges of 50 m. Stationary dune buggies have been monitored with engines "revved" at high speed with subsequently high sound pressure levels for durations exceeding 5 minutes

(Bondello and Brattstrom, 1978). Many dune buggies have been observed repeatedly traversing the same area of sand dunes within a one hour period. Wide-ranging dune buggies were observed deep within the dune interior, repeatedly crossing the same terrain. Dune buggies, then, may be characterized by high engine speed (high sound pressure level) activities, which often range widely over the dune systems, with repeated passages over selected terrain. When these intensely concentrated dune buggy activities on sand dunes are viewed (especially at ORV playgrounds such as Glamis, California), it becomes quite apparent that the cumulative acoustical dosages delivered at any one spot on the dunes system during an active spring or summer weekend morning are at least as great as those delivered to the lizards in this study. Thus, these high-intensity sounds are a regularly occurring phenomena in the California desert regions during the spring and summer months.

The major energies of dune buggy sounds (Figure 1) coincide with the frequencies of maximum acoustical sensitivity for Uma scoparia, 1000-1600 Hz, as determined by Werner (1972). Uma notata notata, the Colorado Fringe-Toed Lizard, has a similar maximum acoustical sensitivity range, 1000-2000 Hz, and responds to intense acoustical stimulation (Wever and Peterson, 1963) in a pattern not unlike those described for Uma scoparia in this report (Figure 4). Thus, these data suggest that dune buggy sounds are inherently damaging to the hearing sensitivity of Fringe-toed lizards.

Fringe-toed lizards are completely restricted to the fine, loose, wind-blown sand of desert dunes, riverbanks, and washes (Stebbins, 1966). Fringe-toed lizards, then, are unable to successfully leave their sandy habitat, and are incapable of evacuating the habitat most heavily impacted by dune buggies.

When disturbed in the field, Uma scoparia seldom escaped into deep burrows. Of the 20 Uma scoparia captured for this study, not one sought the refuge of nearby rodent burrows. Many hid among surface vegetation or burrowed

only a few millimeters below the sand surface, often at the mouth of a rodent burrow. When Uma scoparia were pursued, their quick turn into the mouth of a burrow and rapid shallow burial near the entrance gave the impression of escape into the deep rodent burrow. Repeatedly, however, the lizards were found just beneath the surface near the entrance of the burrow. Similar escape strategies have been described for several species of Uma. Pough (1970) described shallow burial (less than 2 cm deep) or retreat beneath bushes as the escape responses of Uma notata to predators. He also described the tendency for Uma to preferentially locate themselves at sand depths of no more than 4 cm from the surface. Commins and Savitsky (1973) observed Uma exsul when approached to "sand swim," hide beneath tumble weeds, or lie motionless and cryptically colored on sand surfaces. Carpenter (1967) noted a tendency for Uma exsul to shallowly burrow near rodent burrow entrances.

Uma will seek the refuge of rodent burrows when soil and climatic conditions are favorable. In damp, compacted soil which receive summer rainfall (Kelso Dunes in 1967) conditions were favorable for the maintenance of rodent burrow systems and Uma scoparia retreated to them rather than bury themselves in sand (Pough, 1970). Carpenter (1967) noted a similar tendency for Uma exsul and Uma parapygas to preferentially retreat to rodent burrows rather than sand swim. Uma constructed its own burrows in moist sand under laboratory conditions (Pough, 1970).

When soil and climatic conditions are less favorable (less cohesive, dry, windblown sand) fewer rodent burrows are maintained. During such conditions (Palm Springs, Panorama, in 1968) fewer burrows were available as retreats. Because of the territorial behavior of Uma, crowding into burrows would probably not occur (Pough, 1970). Thus, more Uma will be forced to seek refuge outside of burrows during seasons of low burrow availability.

A shallowly buried lizard is more likely to receive a higher intensity sound exposure from a nearby dune buggy than would a deeply burrowed lizard.

Our laboratory observations indicate that 4 cm of fine compacted sand from Rice, California, does not noticeably lower the sound pressure level of a 95 dBA sound. Thus, due to restricted species distribution and shallow and surface escape tendencies, fringe-toed lizards are particularly prone to receive damaging, short-duration exposures of recurring dune buggy sounds. These exposures may be most intense during the most active ORV months of the spring and summer seasons.

Intense ORV activities of the spring and summer months, however, coincide with the reproductive season of all three species of Uma which occur in California. Uma inornata are reproductively active from March to September (Mayhew, 1965), Uma notata from April to September (Mayhew, 1966a), and Uma scoparia from April to July (Mayhew, 1966b). All California species of Uma apparently reach their peak of reproductive activities in May (Mayhew, 1965, 1966a, 1966b). Thus, during the most critical phase of their life cycle, the breeding season, their habitat is subjected to the most intense degree of ORV impact.

When favorable environmental conditions (proper winter rains and abundant annual plant bloom) do not occur, Uma's preferred annually migrating insect prey may be scarce on the dunes. Uma are then forced to switch to a less easily obtained insect prey which frequent perennial plants. Their lowered energy intake may delay and subsequently decrease the reproductive success of Uma for the entire season. If such conditions (drought) persist for several seasons, population sizes of Uma may be reduced (Mayhew, 1966b). Thus, the potential impacts of ORV's on Uma are especially high during conditions of drought, wherein populations are reduced in size and fewer rodent burrows are available as retreats. At these times of extreme dryness, and low annual plant bloom, the dune habitat of fringe-toed lizards are most sensitive to ORV impact.

The importance of hearing to Uma is probably related to prey acquisition and predator avoidance. Environmental sounds of potential importance; rustling

of dry leaves by insects, digging and sniffing of dogs, crawling snakes on loose gravel, striking rattlesnakes, and swooping owls all produce low-intensity sounds which have strong components within the range of 1000-4000 Hz. These potentially important sounds coincide with the maximum acoustical sensitivities (900-3500 Hz) of lizards of the families Iguanidae, Gekkonidae, Anguidae, and Teiidae (Campbell, 1969). The sensitivities of lizards to these specific frequencies certainly implies that a great selective advantage is gained in detecting these subtle environmental sounds.

Good hearing ability is especially important for animals that inhabit quiet natural environments such as the desert where ambient sound pressure levels are often as low as 30 dBL (Bondello and Brattstrom, 1978). The attenuation of sounds due to increased temperature and decreased humidity (Harris, 1967) makes the desert an especially quiet environment. The regions within the perimeter of long, continuous sand dunes such as the Algodones Dunes, the largest in California and habitat of Uma notata (Norris, 1958) are especially quiet due to the establishment of shadow zones of suppressed noise. In these regions, the sand dunes act as a barrier preventing the intrusion of high-intensity ground generated noise similar to acoustical barriers constructed near freeways (Federal Highway Administration, 1976). Due to the rapid attenuation of higher frequency sounds, reception of natural sounds above 1000 Hz implies nearness and often danger to prey animals (Hardy, 1956). Thus, the importance and selective advantage of possessing and maintaining a healthy hearing apparatus capable of detecting subtle sounds within the 900-3500 Hz range for fringe-toed lizards as well as other desert animals is again strongly implied.

The extreme vulnerability of the hearing apparatus of Uma scoparia to short durations of high-intensity sound is not demonstrated in humans. Human noise exposure limits set by the Occupational Safety and Health Administration

(OSHA) prescribe a recommended cumulative exposure to 95 dBA noise not to exceed four hours. Uma scoparia suffered hearing loss with a cumulative exposure of 500 seconds to 95 dBA sounds. Thus, the larger, more sophisticated, better protected human ear is capable of withstanding high-intensity sound exposures which easily damage the smaller, more simplistic lizard ear. OSHA and EPA recommended noise guidelines established for the protection of human hearing, then, are not necessarily applicable to the protection of wildlife hearing. An acceptable vehicle noise limit in urban areas may, in a relatively short period of time, be capable of severely damaging the hearing of exposed wildlife populations.

Awareness of these pronounced differences between human and desert vertebrate auditory systems, the relative vulnerability to acoustical trauma of desert species, the importance of the detection of subtle low-intensity sounds in the daily lives of wildlife, the significance of the 900-3500 Hz sensitivity range, the relative quiet of remote natural areas, all are fundamental to the specific understanding of the effects of dune buggy sounds on Uma scoparia, and more generally, to the effects of high-intensity mechanized sounds on wildlife. Unless these fundamental aspects are realized and addressed the ecological significance of this report, or any similar investigation concerning the effects of noise on wildlife, will not be recognized.

Recommendations of this report are that dune systems with known populations of fringe-toed lizards be immediately considered as "sensitive" areas, especially during times of drought and subsequent low annual productivity. All unnecessary disturbances (ORV activity, mining, repeated low jet overflights, gunnery) should be immediately restricted from the immediate vicinity of these dune systems. This report does not mean to imply that habitat

disturbance of a non-acoustical nature (grazing) should not also be restricted from these areas. Indeed, as sensitive areas, the dune system is especially fragile to a variety of disturbances. We simply state, that considering the acoustical data, alone, the animals of the dune systems, especially those of the interior "shadow zone" are particularly vulnerable to mechanized acoustical intrusion and we, therefore, recommend the restriction of high-intensity sound activities from these areas.

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CONCLUSION

Dune buggy sounds of 95 dBA (100 dBL) and a cumulative exposure time of 500 seconds severely impaired the hearing of Mojave Fringe-Toed Lizards. These sounds were equivalent to those actually monitored in the desert at distances of 50 meters. Shallow burial in sand was not considered an adequate escape of these lizards from ORV sounds. The natural history of Fringe-Toed Lizards, reproductive cycles, and total dependence on adequate annual plant growth and insect migration for species survival is briefly summarized.

The attenuation of sounds in hot, dry desert climates is described. The relative importance of the reception of sounds by prey animals, especially in the ranges below 3000 Hz, is discussed with reference to the optimal hearing ranges of desert lizards (1000 - 3000 Hz). The importance of the auditory sense to these desert animals is implied.

Implications of the high-intensity sounds generated by a number of mechanized activities (ORV, mining, gunnery, ~~low~~ aircraft overflight) to the wildlife of quiet desert regions are made, especially concerning the effects of ORV sounds on predator detection abilities of prey animals. Protection of Fringe-Toed Lizards and their dune habitat is advised.

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EXPERIMENT III

The Effects of Dune Buggy Sounds on Behavioral Hearing
Thresholds of Desert Kangaroo Rats, Dipodomys deserti

by

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ABSTRACT

Stereotypic behaviors are described for 14 Desert Kangaroo Rats, Dipodomys deserti, alone in enclosures and during 87 encounters with live Sidewinders, Crotalus cerastes. Two kangaroo rats were also observed alone and during encounters with a coiled, freeze-dried Western Rattlesnake, C. atrox. These rats responded to the presence of the freeze-dried snake by shifting from normal maintenance activities to pronounced intruder-awareness behaviors. Sand kicking was a stereotypic response of D. deserti to all intruders.

Sand kicking was also elicited in response to the reception of recorded faint sounds of a crawling Sidewinder by D. deserti. Behavioral hearing thresholds of two kangaroo rats were determined by eliciting this response to these low-intensity sound stimuli.

Behavioral hearing thresholds of two kangaroo rats were determined before and after exposures to 95 dBA (100 dBL) dune buggy sounds for 500 seconds. These sounds immediately reduced hearing sensitivities, by as much as 10 dBL in one subject. Hearing sensitivities were gradually recovered, with both rats regaining their original acuity 21 days after sound exposures.

These results were correlated with reported striking ranges of rattlesnakes. Correlations indicated that both kangaroo rats became more vulnerable to nocturnal predation due to reduction of auditory predator detection ranges.

Disruption of natural populations of kangaroo rats due to increased ambient sound levels or hearing impairment is discussed in reference to ORV activities on desert sand dunes. Indigenous sand dune inhabitants are concluded to be unable to tolerate ORV impacts.

INTRODUCTION

The increased activities of off-road vehicles (ORV's) in the California Desert have caused considerable physical damage to the soils, vegetation, and wildlife of this region (Sheridan, 1979). Bondello and Brattstrom (1978) reported the concomitant spread of high-intensity sounds, generated by ORV's into these formerly quiet remote desert regions and warned of the threat ORV sounds pose to the well-being of the indigenous wildlife of these arid regions.

Bondello (1976) showed that excessive off-road motorcycle sounds (115 dBA) could damage the acoustical sensitivity of Desert Iguanas, Dipsosaurus dorsalis. The early emergence of Couch's Spadefoot Toads, Scaphiopus couchi, from safe burrows during improper times of the year and under inadequate surface conditions, was also shown to be elicited by off-road motorcycle sounds (95 dBA) of varying durations (Bondello and Brattstrom, 1979). Recently, auditory evoked response techniques revealed that Mojave Fringe-Toed Lizards, Uma scoparia, suffered severe hearing losses after brief exposures (500 seconds) of 95 dBA dune buggy sounds (Bondello, Huntley, Cohen, and Brattstrom, 1979). The experimental evidence clearly suggests that the hearing of desert vertebrates, especially those that reside on or near sand dunes, are particularly vulnerable to ORV sounds.

Desert Kangaroo Rats, Dipodomys deserti, are typical residents of sand dune systems of the California Desert. Among the 13 species of kangaroo rats within California (Ingles, 1965), D. deserti is considered the most specialized form (Nader, 1978).

Adaptations of kangaroo rats to arid environments include a variety of anatomical and physiological specializations. Among these specializations are adaptations for ricochetal locomotion (Hatt, 1932; Howell, 1932;

Bartholomew and Caswell, 1951), water metabolism and conservation (Schmidt-Nielsen and Schmidt-Nielsen, 1951), tolerance to high body temperatures (Dawson, 1955), diestrous reproductive cycles (Nader, 1978), and subcortical control of hind limbs to facilitate rapid leaping motions (Strauss, 1936).

The ear apparatus of kangaroo rats represents an equally specialized adaptation to quiet arid regions (Webster, 1972). The middle ear cavities of Merriam Kangaroo Rats, D. merriami, are reported by Webster (1961) to be greatly enlarged, with a total volume greater than that of their braincase. This greater volume lowers the air pressure within the middle ear, which reduces the effect of dampening on sounds that strike the tympanic membrane (Webster, 1963). The middle ear ossicles are delicately suspended within the middle ear cavity and freely move, unencumbered by supportive ligaments common to most other mammals (Webster, 1961). The malleus is greatly lengthened and extends down over the large tympanic membrane, acting as a lever arm that transforms the relatively weak vibrations that strike the tympanic membrane into stronger movements as the vibrations move down the ossicular chain of the middle ear. Due to the large size of the tympanic membrane and the small size of the footplate of the stapes, weak pressure on the large tympanic membrane is transformed into strong pressure on the oval window. This "transformer ratio" is extremely high in D. merriami, around 97.2 : 1 and is relatively low in man, around 18.3 : 1. The specializations of the middle ear apparatus of Dipodomys, enlarged auditory bullae, freely moving middle ear ossicles, and high transformer ratios all act to greatly amplify sounds (nearly 97 times) and relay these vibrations into the inner ear (Webster, 1961).

The inner ear of kangaroo rats is also modified to receive and convert these vibrations into nervous impulses. The cochlear duct has 4 1/4 turns, 2 1/2 turns are common in mammals. Within the cochlear duct

the tectorial membrane is suspended over enlarged cells of Hensen, with only the "hairs" of the hair cells delicately embedded in the membrane. Thus, the inner ear is adapted for increased sensitivity to the reception of faint sound vibrations (Webster, 1961).

The central auditory system of D. merriami shows modifications of the nervous pathways to the brain (Webster, Ackerman, and Longa, 1968), which are well correlated to those peripheral ear modifications just described. Nuclei of the central auditory system of kangaroo rats are prominent, with special enlargement of medial superior olivary nuclei and dorsal nuclei of the lateral lemniscus also apparent. The dorsal cochlear nuclei are organized into three cell-type layers, which comprise the majority of the acoustica. Two types of spindle-shaped cells of the lateral and medial superior olivary nuclei are present as are unique groups of large multipolar cells that lie between the dorsal nuclei of the lateral lemniscus and base of the inferior colliculus. The adaptations of the central auditory system of kangaroo rats, therefore, serve to sufficiently strengthen and shorten their auditory pathways in order to rapidly relay acoustical information to the brain.

Cochlear microphonic studies on D. merriami showed the greatest sensitivities of their ears to occur between 1.0 - 3.0 KHz, with peak sensitivities at 1.2, 1.4, 1.8 - 2.2, and 2.6 KHz (Webster, 1962). Good sensitivity to low frequency sounds was also seen by Moushegian and Rupert (1970) wherein 89% of nerve fibers studied in the ventral cochlear nucleus of kangaroo rats had their best frequency responses below 4.0 KHz.

The importance to kangaroo rats of detecting low-frequency, low-intensity environmental sounds has been shown by Webster (1962) and Webster and Webster (1971). Sounds produced by predators of D. merriami,

Sidewinders, Crotalus cerastes, and Screech Owls, Otus asio, although quite faint, were strongest within the range of 1.0 - 3.0 KHz. The

reception of the sounds of these predators approaching, the snake crawl and strike, the owl's wing beat, provided kangaroo rats ample warning to successfully evade capture, while hearing-impaired rats were captured. Thus, through processes of natural selection, which operate in quiet desert environments, kangaroo rats have adapted their unique ear and brain modifications which enable them to receive and rapidly process low-intensity sounds of critical environmental importance.

Behavioral experiments to determine hearing thresholds of kangaroo rats were not as productive as electrophysiological methods. Webster and Webster (1972) report their inability to shape naturally-occurring behaviors of D. merriami to fit their experimental conditions for the purposes of evaluating behavioral hearing thresholds. Using shock avoidance techniques, they had great difficulties in obtaining suitable auditory thresholds. Kangaroo rats were apparently too active to adjust to shock avoidance training without producing disruptive behavioral artifacts.

It was, therefore, the purpose of this study to attempt four separate observational experiments on Desert Kangaroo Rats in order to isolate a specific behavioral response to acoustical stimuli and employ this response as a means of determining the hearing thresholds of D. deserti. These four experiments were to:

- 1) Observe and describe typical behaviors of solitary Desert Kangaroo Rats in hopes of detecting a behavior which could be shaped as a response to auditory stimuli.
- 2) Observe the typical behaviors of Desert Kangaroo Rats exposed to live Sidewinders in order to describe their reactions during predator-prey encounters.
- 3) Determine the hearing sensitivity of Desert Kangaroo Rats by eliciting naturally-occurring behavioral responses to auditory stimuli.

4) Determine the behavioral hearing thresholds of Desert Kangaroo Rats by the same methodology as previously, after their exposure to brief episodes of 95 dBA dune buggy sounds.

Thus, we attempted to determine, through behavioral means, the effects of dune buggy sounds on the hearing of Desert Kangaroo Rats. In an early phase of the experiment, it became apparent that a naturally-occurring behavior, a sand kick, was elicited from D. deserti, whenever an intruder (i.e. the experimenter) was detected. Subsequent encounters with Sidewinders by D. deserti were also seen to elicit this response. Thus, we endeavored to shape the experimental conditions to fit the presentation of this response into a situation whereby we could properly evaluate the hearing sensitivity of D. deserti. The use of this naturally-occurring response as a criterion of behavioral hearing, and the relative success of this method over shock avoidance experiments as a means of evaluating Desert Kangaroo Rat hearing, and the potential ecological effects of ORV activities on desert sand dune habitats are now described.

MATERIALS AND METHODS

Fourteen Dipodomys deserti were captured with Sherman Live Traps 5 kilometers south of Rice, Riverside County, California, on 8 August 1978. Kangaroo rats were placed into large glass Mason jars, supplied with cotton and bird seed, and packed into a specially-constructed acoustically-insulated wooden box that was lined on all sides with 3-inch thick foam rubber pads. This box could reduce a 90 dBA sound by 35 dBA. Animals were immediately transported to California State University, Fullerton, Orange County, California. Here, they were transferred into individual plastic containers with internal dimensions of 13 x 15 x 27 centimeters covered by a $\frac{1}{4}$ inch mesh wire screen. These containers held a substrate of fine sand collected from the home dunes near Rice. The individual containers were stored 5 across on shelves of a specially-assembled "igloo" of six-inch thick styrofoam blocks. Internal dimensions of each shelf were 20 x 100 x 100 centimeters. The subjects were therefore acoustically insulated on all sides, top and bottom. This "igloo" could also reduce a 90 dBA external sound by 35 dBA.

Rats were maintained in total darkness within the "igloo", except for a daily exposure to light around dusk, when the "igloo" was opened to feed the animals. Animals were supplied a daily ration of bird seed and occasionally fresh lettuce. Cotton and a small jar were also provided each rat. The soil was periodically strained to remove droppings and seed husks and occasionally replaced. A Yellow Springs Instrument Company Telethermometer Model 44D with four thermister probes monitored the internal temperature of each shelf of the "igloo". These temperatures fluctuated daily from around 22⁰ C during morning hours to 27⁰ C during evening hours. This daily temperature increase was correlated with an increased state of activity for the rats, as monitored by a Res Alarm

Model MD 1A motion detector connected to a specially-fabricated battery-powered event counter. Rats maintained these behavioral activity cycles throughout their captivity.

Observations of kangaroo rat behavior were conducted over a four month period from August to December 1978 for one to several nights a week between 1900 - 2400 hours. Kangaroo rats were observed within a 110 gallon aquarium that had been acoustically-insulated with 3-inch thick pads of foam rubber attached to top, sides, and floor of the enclosure. The enclosure was filled with 10 centimeters of fine sand from the home dunes near Rice. Four thermisters of the tele-thermometer monitored the ambient temperature of the enclosure which seldom varied from 22⁰ C. A Bruel and Kjaer 2203 Precision Sound Level Meter with 1613 Octave Band Selector and cable condenser microphone monitored the ambient sound level of the enclosure. Depending on the activities within the building, these sound levels fluctuated from a minimum of 22 dBA (52 dBL), corresponding to the same levels recorded at the Rice Valley sand dunes at 2200 hours, up to a maximum of 34 dBA (61 dBL). Most sound levels were near 33 dBA $\pm$ 1 dB. The enclosure was illuminated by a dim red light, placed between the observer and enclosure, directed into the enclosure.

Solitary kangaroo rats were observed over a two month period and their stereotypic behaviors described. A behavioral classification scheme was then developed for later use in tabulating the frequencies and sequences of occurrence of these behaviors.

Over the same time period, kangaroo rats were placed into the enclosure which contained a live Sidewinder, Crotalus cerastes, in order to observe their typical behaviors during these encounters. A total of 87 individual encounters between 14 kangaroo rats and

2 Sidewinders (38 and 45 centimeters snout-vent length) were observed. Individual behaviors of each animal were described for these encounters and tape recordings of sounds emitted during these interactions were recorded for later sonagraph analysis on a Uher 4000C portable tape recorder. Again, behavioral classification schemes were developed for later use in tabulating frequencies and sequences of occurrence of specific behaviors for the rats during simulated encounters using a freeze-dried Western Rattlesnake, Crotalus atrox. Behaviors of the Sidewinders were tabulated during actual encounters with kangaroo rats.

Two kangaroo rats were later observed to determine frequencies and sequences of specific behaviors that occurred when the rats were alone in the enclosure and when the rats were in the presence of the freeze-dried, coiled C. atrox. A total of 250 movements were observed for each rat alone and with the snake. Thus, a total of 500 movements were observed and tabulated for each condition and from these the frequencies (expressed as percentages of total movements) and sequences of occurrence of these behaviors were determined.

During encounters with either live or freeze-dried rattlesnakes kangaroo rats were observed to deliver well-placed kicks of sand at the intruder. These sand kicks were not delivered until the snake was detected. This sand kicking behavior was, therefore, selected for use as behavioral criteria which signalled when a kangaroo rat detected an intruder. Because the rats have a variety of special sensory capabilities (visual, acoustical, olfactory, tactile) which could detect the presence of a snake, the following experimental design (Fig. 1) was conceived in order to evaluate the relative effectiveness of each alerting sensory system, and eventually to isolate the responses of kangaroo rats to acoustical stimuli only, as a means of measuring

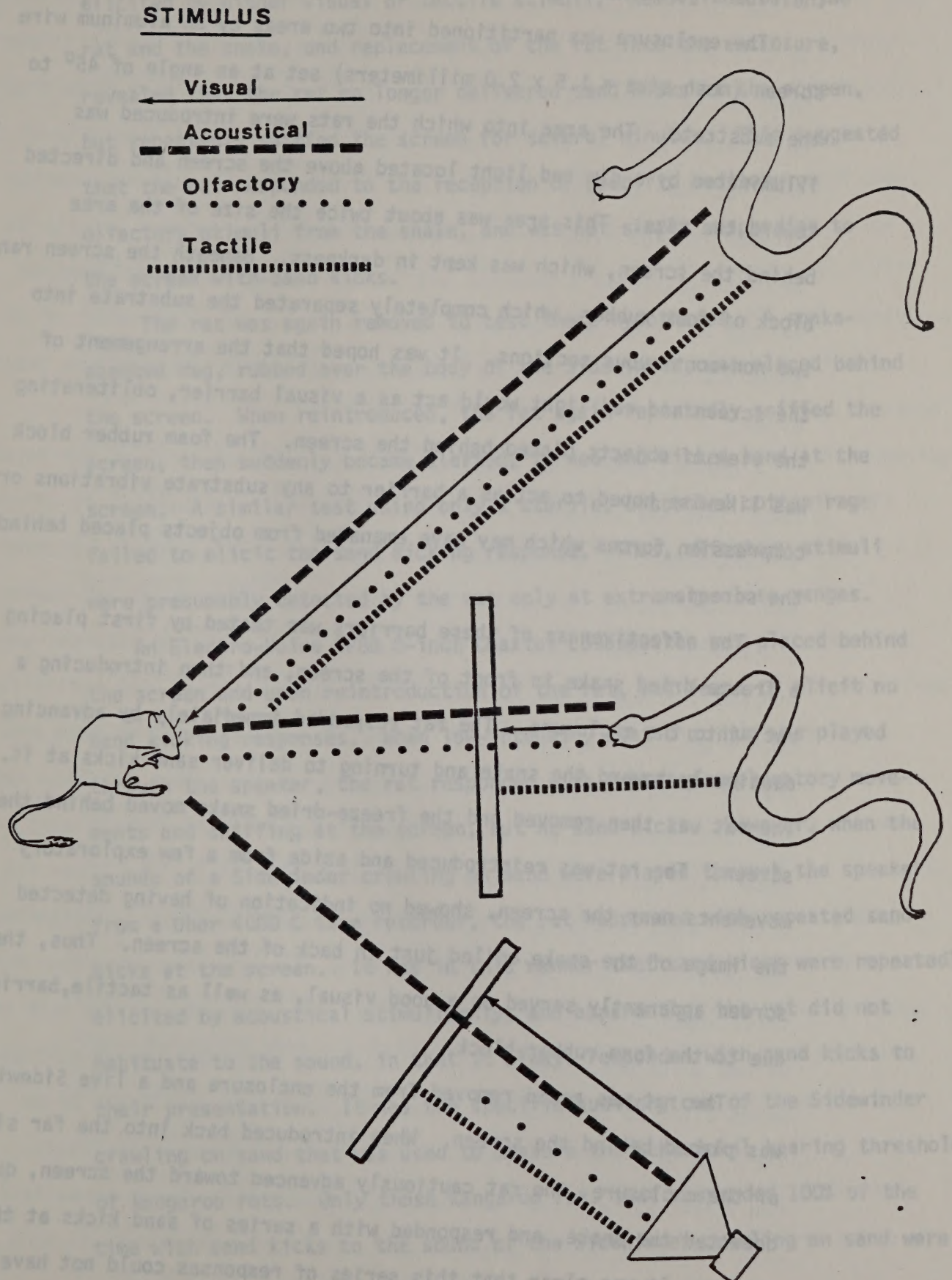


Figure 1: Diagram depicting the Behavioral Hearing Experimental Design.

their behavioral hearing thresholds.

The enclosure was partitioned into two areas by an aluminum wire screen (mesh size = 1.5 x 2.0 millimeters) set at an angle of 45° to the substrate. The area into which the rats were introduced was illuminated by a dim red light located above the screen and directed toward the rats. This area was about twice the size of the area behind the screen, which was kept in darkness. Beneath the screen ran a block of foam rubber, which completely separated the substrate into two non-continuous sections. It was hoped that the arrangement of the screen and red light would act as a visual barrier, obliterating the view of objects placed behind the screen. The foam rubber block was likewise hoped to act as a barrier to any substrate vibrations or compression forces which may have emanated from objects placed behind the screen.

The effectiveness of these barriers was tested by first placing a freeze-dried snake in front of the screen, and then introducing a rat into the enclosure. The rat responded immediately by advancing cautiously toward the snake and turning to deliver sand kicks at it. The rat was then removed and the freeze-dried snake moved behind the screen. The rat was reintroduced and aside from a few exploratory movements near the screen, showed no indication of having detected the image of the snake coiled just in back of the screen. Thus, the screen apparently served as a good visual, as well as tactile, barrier due to the foam rubber block.

The rat was again removed from the enclosure and a live Sidewinder was placed behind the screen. When introduced back into the far side of the enclosure, the rat cautiously advanced toward the screen, quickly detected the snake, and responded with a series of sand kicks at the screen. It was clear that this series of responses could not have been

elicited by either visual or tactile stimuli. Removal of both the rat and the snake, and replacement of the rat into the enclosure, revealed that the rat no longer delivered sand kicks at the screen, but repeatedly sniffed the screen for several minutes. This suggested that the rat responded to the reception of specific auditory or olfactory stimuli from the snake, and was not simply responding to the screen with sand kicks.

The rat was again removed to test these hypotheses. A snake-scented rag, rubbed over the body of the Sidewinder, was placed behind the screen. When reintroduced, the rat again repeatedly sniffed the screen, then suddenly became alerted, turned and kicked sand at the screen. A similar test using only a sterile, unscented cotton rag failed to elicit the sand kicking response. Thus, olfactory stimuli were presumably detected by the rat only at extremely close ranges.

An Electro-Voice SP8B 8-inch Coaxial Loudspeaker was placed behind the screen and upon reintroduction of the rat, was found to elicit no sand kicking responses. When low-intensity static or hum was played through the speaker, the rat responded with repeated exploratory movements and sniffing at the screen, but no sand kicks. However, when the sounds of a Sidewinder crawling on sand were played through the speaker from a Uher 4000 C tape recorder, the rat responded with repeated sand kicks at the screen. It was in this manner that sand kicks were repeatedly elicited by acoustical stimuli only, and apparently, the rat did not habituate to the sound, in that it always responded with sand kicks to their presentation. It was the specific auditory cue of the Sidewinder crawling on sand that was used to measure the behavioral hearing threshold of kangaroo rats. Only those kangaroo rats that responded 100% of the time with sand kicks to the sound of the Sidewinder crawling on sand were used in the behavioral hearing tests.

Due to the fluctuation of ambient sound levels within the enclosure by 1 or 2 dB, a more accurate method of assessing the stimulus intensity used in the behavioral hearing tests was devised. A Fluke 8120A Digital Multimeter, used as a millivoltmeter, was connected in line between the tape recorder and the speaker. This arrangement allowed the precise speaker voltage which elicited the sand kicking responses of rats to be measured. When a response was first elicited, the exact speaker voltage was recorded, and after removal of the rat, the number of dB above ambient of the sound produced by this speaker voltage was determined.

A typical behavioral hearing test began soon after a rat was introduced into the enclosure. When its explorations brought it to within 50 centimeters of the speaker, the tape recorder was quietly started and volume slowly turned up, from the minimum setting, at increments of 0.5 mvolts. When the first sand kick was observed, the recorder was stopped, voltage noted, and volume turned down again. The entire procedure was then repeated until several consistent readings were obtained. The two Desert Kangaroo Rats used were quite consistent in these responses, and fortunately did not deliver sand kicks until the stimuli were presented. Other rats had responded with continuous sand kicks, long after the stimuli were terminated. Control experimental sessions to determine the behavioral hearing thresholds of the two rats were conducted for three weeks prior to 20 November 1978. The responses of the rats remained quite consistent from week to week, thus, the lowest voltages which elicited their sand kicking responses were considered to be their threshold of behavioral hearing. These voltages and their equivalent sound pressure levels were recorded for later comparison with threshold levels obtained after the rats were exposed to dune buggy sounds.

High intensity sounds of a 1971 Volkswagen Baja Bug (95 dBA, 100 dBL) were recorded onto a TDK Endless 30-second loop tape, using a battery-powered Panasonic Autostop Cassette Recorder with condenser microphone. A simultaneous recording was made using a Uher 4000C portable tape recorder, for later sonograph analysis. The duration of the dune buggy sound was 25 seconds for every 30 second loop of the tape. Thus, for the 30 second loop tape, the sounds were "on" for 25 seconds and "off" for 5 seconds. The noise exposure was then interrupted and not continuous. Twenty revolutions of the tape were played which resulted in a total sound exposure of 500 seconds (8 minutes and 30 seconds). A Kay Electric Company Sound Spectrograph set on "normal" analyzed the relative intensity distribution of the sounds over the frequency spectrum. A Bruel and Kjaer 2203 sound level meter monitored the overall intensity of the dune buggy sounds.

The dune buggy sounds were played to the kangaroo rats from the loop tape, via the cassette recorder, to a McIntosh Model MI-75 Power Amplifier which amplified the signal through to the Electro-Voice loudspeaker. Signal intensity was increased until 95 dBA (100 dBL) was reached at the position of the kangaroo rat. This intensity is lower than the maximum (105 dBL) value actually recorded from dune buggies in the field (Bondello and Brattstrom, 1978). Exposures were delivered on 20 November 1978.

The rats were housed in a small aluminum screen cage ($\frac{1}{4}$ inch mesh) placed 8 centimeters in front of the speaker during the sounds exposures. Their behaviors were observed during the duration of the sound exposure, after which time their ears were examined with an otoscope to check for any physical signs of external or middle ear damage.

The rats were immediately given a behavioral hearing test after their sound exposures. The rats were then rechecked at weekly periods until 11 December 1978, at which time their recovery was noted.

RESULTS

Observed Behaviors of Desert Kangaroo Rats

The following behaviors and their relative contribution to the total behavioral repertoire of Dipodomys deserti (Table I) were observed for solitary kangaroo rats and rats in the presence of a small, coiled, freeze-dried Western Rattlesnake, Crotalus atrox.

Cautious Stance: All kangaroo rats, when introduced to the enclosure, assumed this alert, stationary posture. The body was slightly crouched, balanced on both ~~hindlimbs~~, with toes widely separated and forelimbs held above with claws widely extended, barely in contact with the substrate. The head was directed forward or slightly to one side, with ears and whiskers quite erect and directed forward. The tail was held near the body, touching the substrate, eyes were widely opened and much sniffing was exhibited. This posture was maintained for several seconds up to as long as five minutes. The cautious stance comprised 39% of the total movements observed in solitary rats, but only 15% of the total movements for rats exposed to a freeze-dried snake.

Exploratory Movements: Kangaroo rats would cautiously explore an area by making short bipedal hops or slow quadrupedal movements. The head was held parallel to the substrate and even with the shoulders with eyes widely opened, ears directed to the sides, whiskers erect, and much sniffing of the area evidenced. Included in this behavior were frequent contacts with the sides of the enclosure and repeated inspection of the foam rubber insulation. Exploratory movements comprised 26% of the total movements observed in solitary rats, but only 11% of the total movements in the presence of the freeze-dried snake.

Table I Frequency of observed behaviors of Dipodomys deserti introduced into a 110 gallon aquarium with and without the presence of a freeze-dried Crotalus atrox. (Each percentage determined by dividing the observed behavior by a total of 500 movements for each condition).

<u>Behavior</u>	<u>Condition</u>	
	<u>without snake</u>	<u>with snake</u>
Cautious	39%	15%
Explore	26%	11%
Forage	12%	1%
Dig	8%	3%
Groom	13%	3%
Slide	2%	3%
Advance	---	20%
Back Leap	---	10%
Sand Kick	---	25%
Avoid	---	5%
Retreat	---	4%

Foraging: Kangaroo rats would often forage for food after performing exploratory movements. The rats would slowly cover an area in a slow quadrupedal movement with head directed downward, sometimes stopping to manipulate and chew small seed-sized objects (foam rubber particles, grit, thread) with forelimbs, rapidly moving and much sniffing observed. Foraging comprised 12% of the total movements observed in solitary rats, but decreased to only 1% of the total for rats in the presence of the freeze-dried snake.

Digging: Following exploratory movements or foraging, kangaroo rats would frequently excavate small pits or trenches in the corners and sides of the flat enclosure. Digging was often rapid, with sand being pushed to the sides and shoved between the raised of the rat, forming a small mound a few centimeters around the rat. Digging comprised 8% of the total movements observed in solitary rats, but only 3% of the total in the presence of the freeze-dried snake.

Grooming: Kangaroo rats rapidly groomed themselves while balanced on hind limbs. Forelimbs frantically moved as the rat scrubbed the head and tail, often chewing at the tail, which was passed between the forelimbs like a rope. This behavior often preceded or followed a cautious stance and was accompanied by periodic sniffing of the area. Grooming comprised 13% of the total movements observed in solitary rats, but only 3% of the total in the presence of the freeze-dried snake.

Sliding: Sand sliding usually accompanied rapid grooming. The kangaroo rat would propel itself headlong through the sand on its side with slow, steady kicks of its hindlimbs. Often, this behavior led back to a cautious stance. Sand sliding comprised 2% of total movements in solitary rats, but increased to 3% of the total observed in the presence of the freeze-dried snake.

An ethogram (Fig. 2A) depicts the sequences of behaviors observed for solitary Desert Kangaroo Rats. The arrows indicate the next behavior which occurred after a given behavior, and percentages indicate the frequency of time a specific sequence occurred after a given behavior. From this ethogram may be seen that the cautious stance is the only behavior which could possibly precede all other behaviors. The cautious stance most often gave rise to exploratory movements (32%) or were self-reinforced (heavy curved arrows) by the adoption of another cautious stance (32%). The cautious stance was adopted at least 32% of the time from all behaviors and in the case of foraging, it was adopted 60% of the time.. Exploratory movements, foraging, digging, and grooming could also precede all behaviors, with the exception of sliding movements. Exploratory movements were self-reinforced 39%, grooming was self-reinforced 25%, and digging was self-reinforced 10% of the time. Foraging and sliding were not self-reinforced in solitary kangaroo rats.

The detection of a live snake, freeze-dried snake, or some clue which suggested the presence of a snake elicited some behaviors not observed in solitary rats. These behaviors included:

Advance to Contact: After detecting the clues indicating the presence of a snake, the kangaroo rat would advance, in several short hops, to within a very close proximity to the source of the clue. The kangaroo rats eyes were widely opened, ears and whiskers quite erect and forward, and much sniffing was exhibited. The kangaroo rat was apparently establishing the exact location of the source through its special sensory capabilities. The advance to contact comprised 20% of the total movements observed in rats in the presence of the freeze-dried snake.

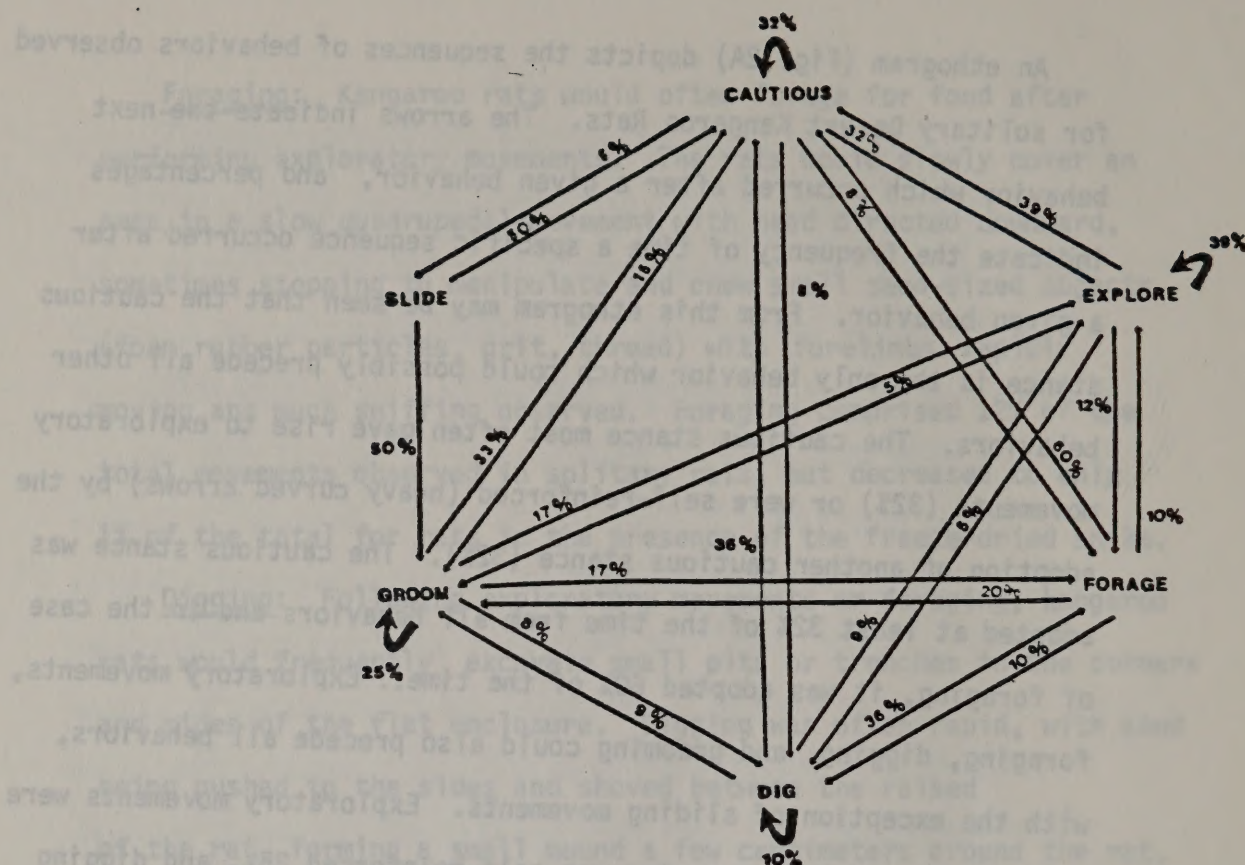


Figure 2A: Ethogram of Solitary *Dipodomys deserti*.

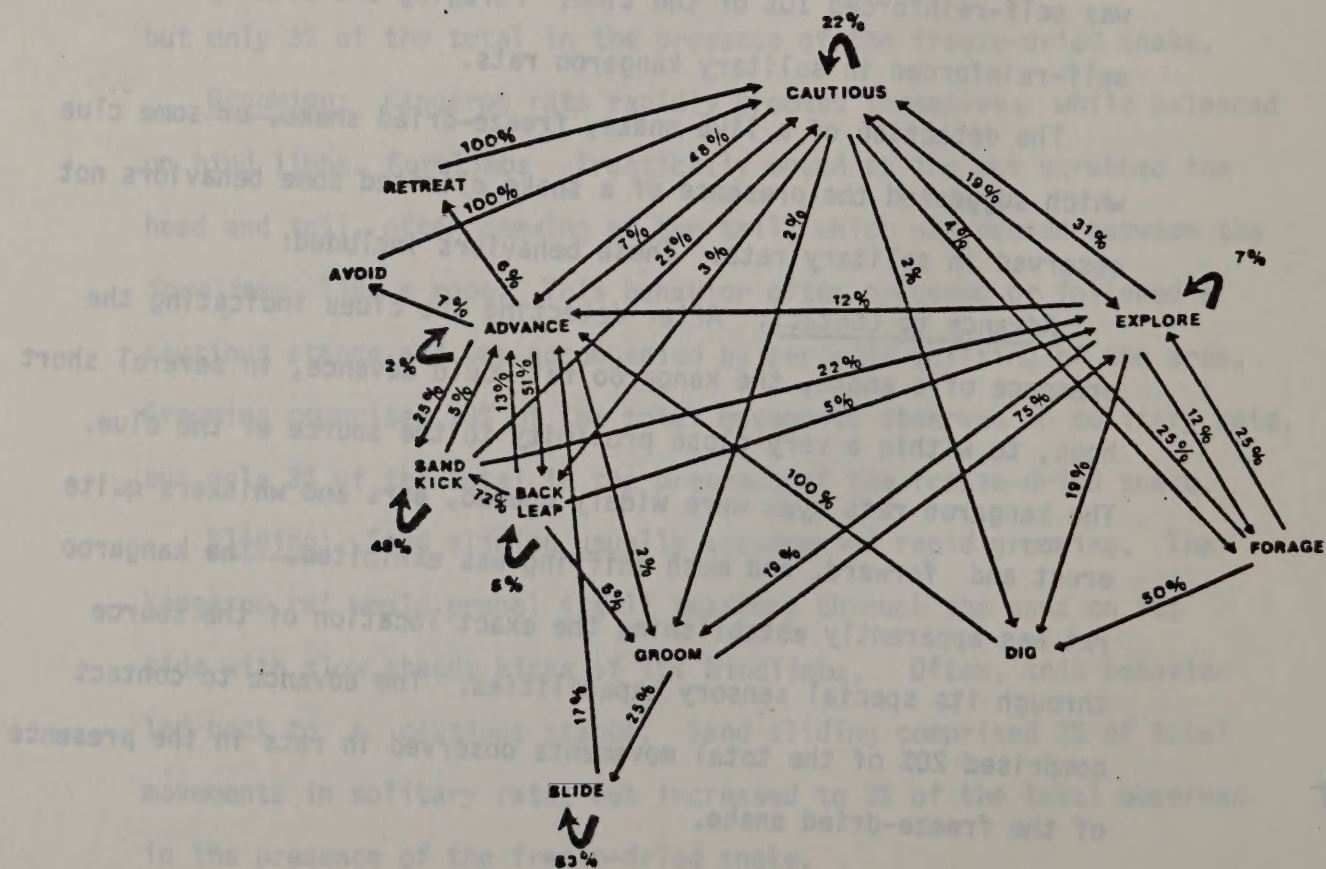


Figure 2B: Ethogram of *Dipodomys deserti* with Freeze-dried *Crotalus atrox*.

Back Leaps: After the location of the source of clues was established, the kangaroo rat would often leap backwards, landing on its hindlimbs 10-20 centimeters from its take-off point. This behavior would often give rise to sand kicks or another advance to contact. Back leaps comprised 10% of the total movements observed in rats in the presence of the freeze-dried snake. This behavior was also observed in tests with live Sidewinders, with back leaps often initiated at the precise instant that the Sidewinder struck out at the rat. Invariably, the kangaroo rat escaped being struck.

Sand Kicks: Once the position of the source of clues was established, the kangaroo rat often withdrew from its immediate vicinity (mostly through back leaps), would face away from the snake, and in a rapid, violent motion, lean forward onto its forelimbs and deliver a well-coordinated, synchronized kick of its hindlimbs, which propelled a good deal of sand in the direction of the snake. Several sand kicks were often delivered in succession, while the rat remained, face away from the snake, with eyes open, and ears and whiskers directed to the side. After several sand kicks, the rat would often turn, assume a cautious stance, advance to contact and if the snake was encountered again, would return to the sand kicking area and kick several more volleys of sand at the snake. This behavior was often repeated for several minutes following the removal of the snake or source of clues. Sand kicks comprised 25% of the total movements observed in rats in the presence of the freeze-dried snake.

Sand kicking is apparently a stereotypic response of the kangaroo rat to the presence of an intruder into the "explored" vicinity of the enclosure. Several other objects, a human hand, the freeze-dried snake, a rag with the scent of a snake, or even a large rock, when

introduced to the enclosure elicited the same response. Some kangaroo rats began sand kicking the moment they were introduced into the enclosure and others would sand kick only infrequently in the presence of a live Sidewinder. These animals were not used in the experimental sessions of this study. Only those kangaroo rats that responded to the presence of an intruder with directed sand kicks 100% of the time were used in the subsequent behavioral hearing experiment.

The accuracy and magnitude of the sand kick deserves mention. After a few seconds of sand kicking, the foam rubber bottom of the enclosure was exposed by the kangaroo rat, the majority of the sand being directed toward the head region of the snake. Sand kicks were quite effective in this respect, with volleys directed with unexpected accuracy into the snakes eyes. Many times Sidewinders were forced to abandon their aggressive pursuit of the kangaroo rats and retire to the corner of the enclosure. Even then, the kangaroo rat would often pursue and harass the snake with well-placed volleys of sand, sometimes causing the snake to attempt to scale the walls of the enclosure, in an apparently futile attempt to withdraw even further from the volleys of sand. The sand kick, therefore, appears to be an effective means of deterring the predatory efforts of Sidewinders.

Avoidance: After an advance to contact, the kangaroo rat would sometimes avoid the snake by turning to one side and keeping the snake in view, quickly hop across the area in front of the snake staying close to the side of the enclosure. This behavior carried the rat to the opposite side of the snake where it invariably assumed a cautious stance with head directed toward the snake. Avoidance comprised 5% of the total movements observed in rats in the presence

of a freeze-dried snake.

Retreat: Sometimes an advance to contact was followed by a direct retreat of the rat. The rat would turn away from the snake and in a series of short bipedal hops or quadrupedal movements withdraw from the immediate vicinity of the snake. Again, this behavior invariably resulted in the assumption of a cautious stance as the rat turned its head back in the direction of the snake. Retreats comprised 4% of the total movements observed for rats in the presence of the freeze-dried snake.

An ethogram (Fig. 2B) depicts the sequences of behaviors observed for Desert Kangaroo Rats in the presence of a freeze-dried snake. As this ethogram shows, the cautious stance can precede all other movements except sand sliding, sand kicks, avoidance, and retreat. The cautious stance most often leads into the advance to contact (48%) and was self-reinforced 22% of the time. The advance to contact and subsequent behaviors (back leaps, sand kicks, avoidance, and retreat) not seen in solitary kangaroo rats are apparently responses of the kangaroo rat to the presence of an intruder. The advance to contact may be assumed from all other behaviors except avoidance, retreat, grooming, and foraging. The advance to contact is self-reinforced only 2% of the time. Behaviors not self-reinforced in the presence of the freeze-dried snake included foraging, digging, grooming, avoidance, and retreat.

Histograms depict the shift in the relative frequency of occurrence of kangaroo rat behaviors alone in the enclosure (Fig. 3A) and in the presence of a freeze-dried snake (Fig. 3B). Among the behaviors observed in the solitary rat, the cautious stance and exploratory movements occurred more often than the maintenance behaviors of grooming, foraging, digging, and sand sliding. In the presence of

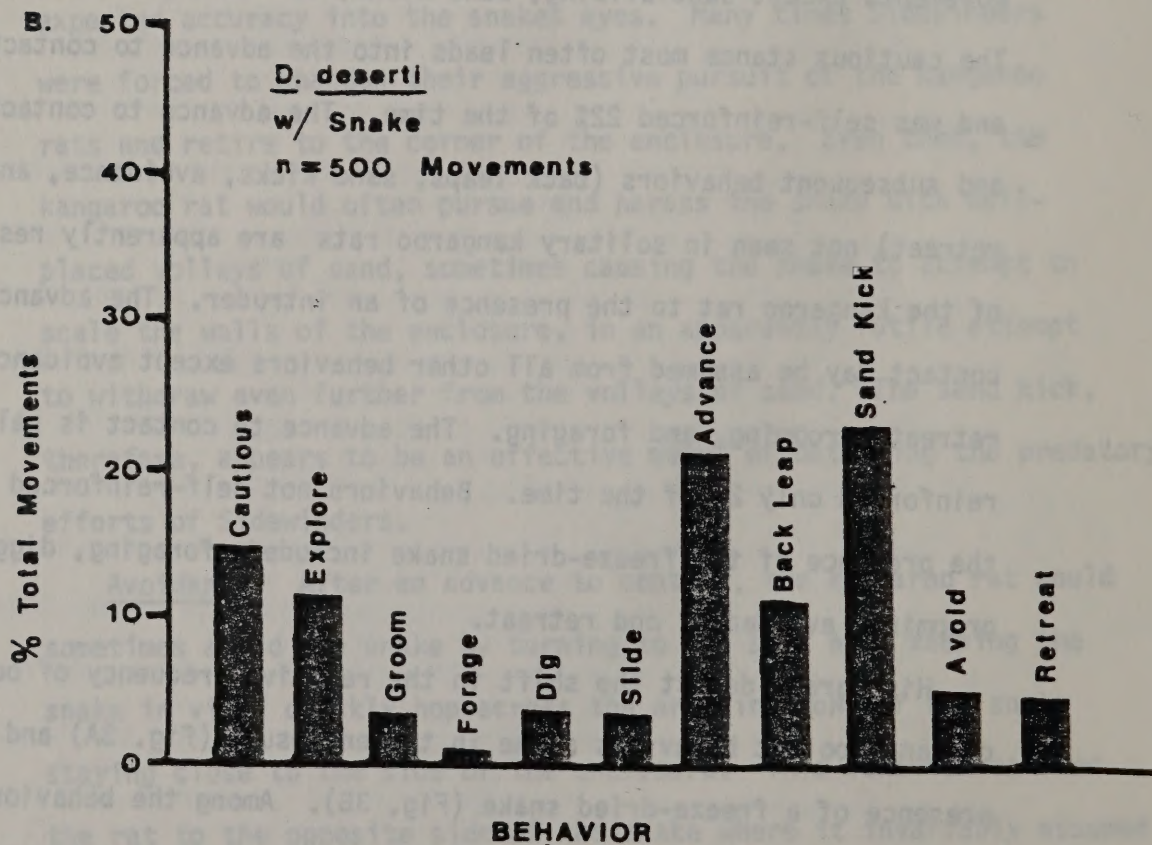
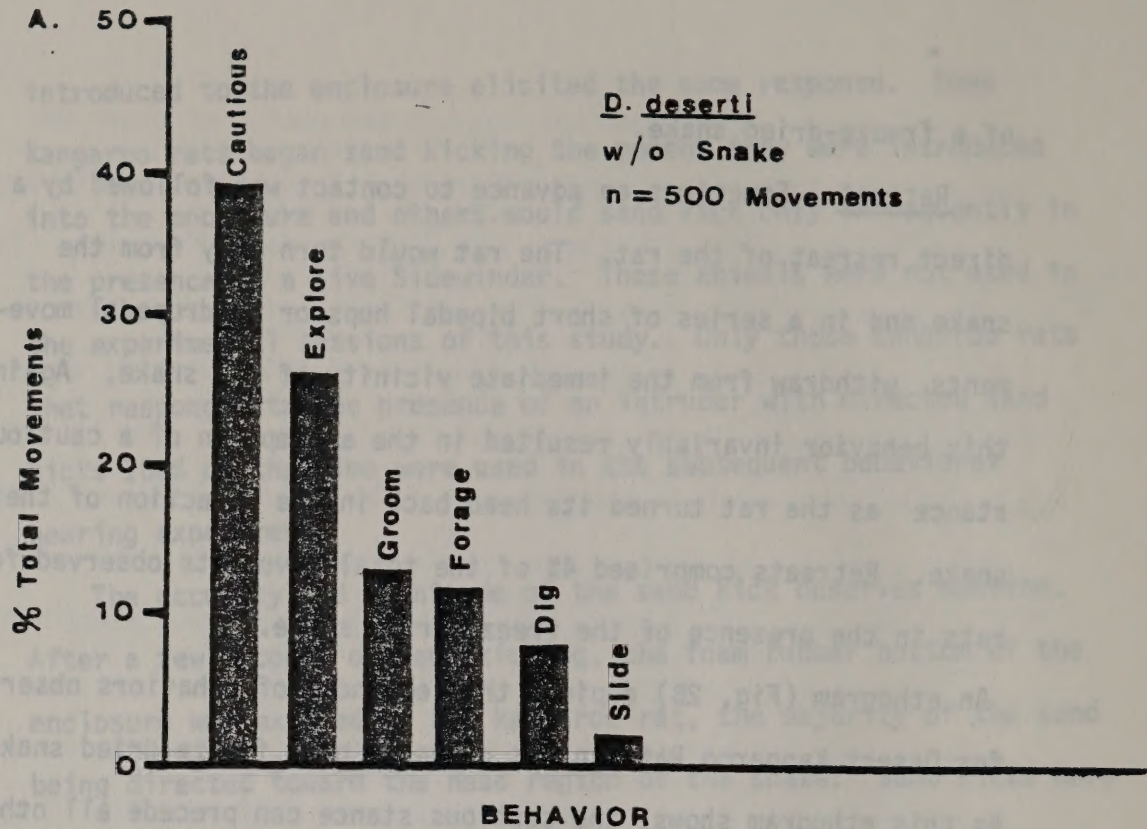


Figure 3: Histograms of behavior of *D. deserti* alone and in the presence of a freeze-dried *C. atrox*.

the freeze-dried snake, the cautious stance and exploratory movements continued to occur more often than the maintenance behaviors, but less often than those behaviors which were in response to the presence of an intruder (advance to contact, back leaps, sand kicks, avoidance, and retreat). Indeed, the sand kick comprised the highest recorded percentage of the total movements (25%) and is self-reinforced 48% of the time. The Desert Kangaroo Rats, then, apparently modified their behavioral patterns upon detection of an intruder by reducing the occurrence of cautious stance, exploratory, and maintenance behaviors, and shifting the majority of its movements to behaviors directed toward encountering and dealing with intruders (advance to contact, back leaps, sand kicks, avoidance, and retreat).

Other behaviors not monitored during the foregoing study were observed in other parts of this report. These behaviors included:

Erratic Leaps: Sometimes, for no apparent reason, kangaroo rats would erratically leap sideways, backwards, or straight into the air. These leaps occurred during times of rapid movement and activity and often when the experimenter attempted to remove the rat from the enclosure.

Escape: After encountering a live Sidewinder, kangaroo rats often performed escape attempts by scurrying up the foam rubber sides of the enclosure, leaping onto screens, or leaping up high enough to contact the roof of the enclosure. Kangaroo rats which displayed this type of behavior prior to the introduction of a Sidewinder (or clues) were not used.

Thumping: After a clue signaling the presence of a Sidewinder was terminated, a kangaroo rat would often retreat to a corner, assume a cautious stance, and with one of its hindlimbs, commence

a series of foot taps. These "thumps" were delivered at intervals of 292 msec to 387 msec ($\bar{x}$ = 318 msec) in a regular manner at sound pressure levels of 45-53 dBA (62-65 dBL) over frequencies which extended up to 8.0 KHz (Fig. 4). Major energies of these "thumps" occurred below 3.5 KHz in the 0.1 - 0.5 KHz range (Fig. 5). Thumping was continued for several minutes by kangaroo rats. The sound of thumping was audible at some distance and sometimes induced other kangaroo rats in nearby cages to begin thumping along with the originator of the thumps. At times, the thumping signal was relayed to as many as four separate kangaroo rats, all of which thumped within their individual cages, the farthest being 6 meters from the originator of the sounds. There was a tendency for kangaroo rats with unbroken, bushy tails to thump more often than those rats with damaged, stubby tails.

Observed Behaviors of Sidewinder Rattlesnakes

The following behaviors and their relative contribution to the total behaviors observed for Crotalus cerastes (Table II) were seen for snakes in the presence of Dipodomys deserti.

Exploratory Movements: A Sidewinder, after a kangaroo rat was introduced into the enclosure, often initiated exploratory movements. The snake would begin a slow, steady, sidewinding crawl toward the rat. The snake's head was raised above the sand and its tongue would often slowly flick in and out of its mouth. Exploratory movements comprised 34% of total movements observed.

Poise: A Sidewinder often preceded or followed exploratory movements by remaining in a loose, stationary, "S"-shaped coil, with head and neck poised in a steady position above the substrate. The tongue was infrequently flicked in and out. The poise comprised 30% of total

TYPE B SONOGRAM © KAY ELECTRIC CO. PINE BROOK, N. J.

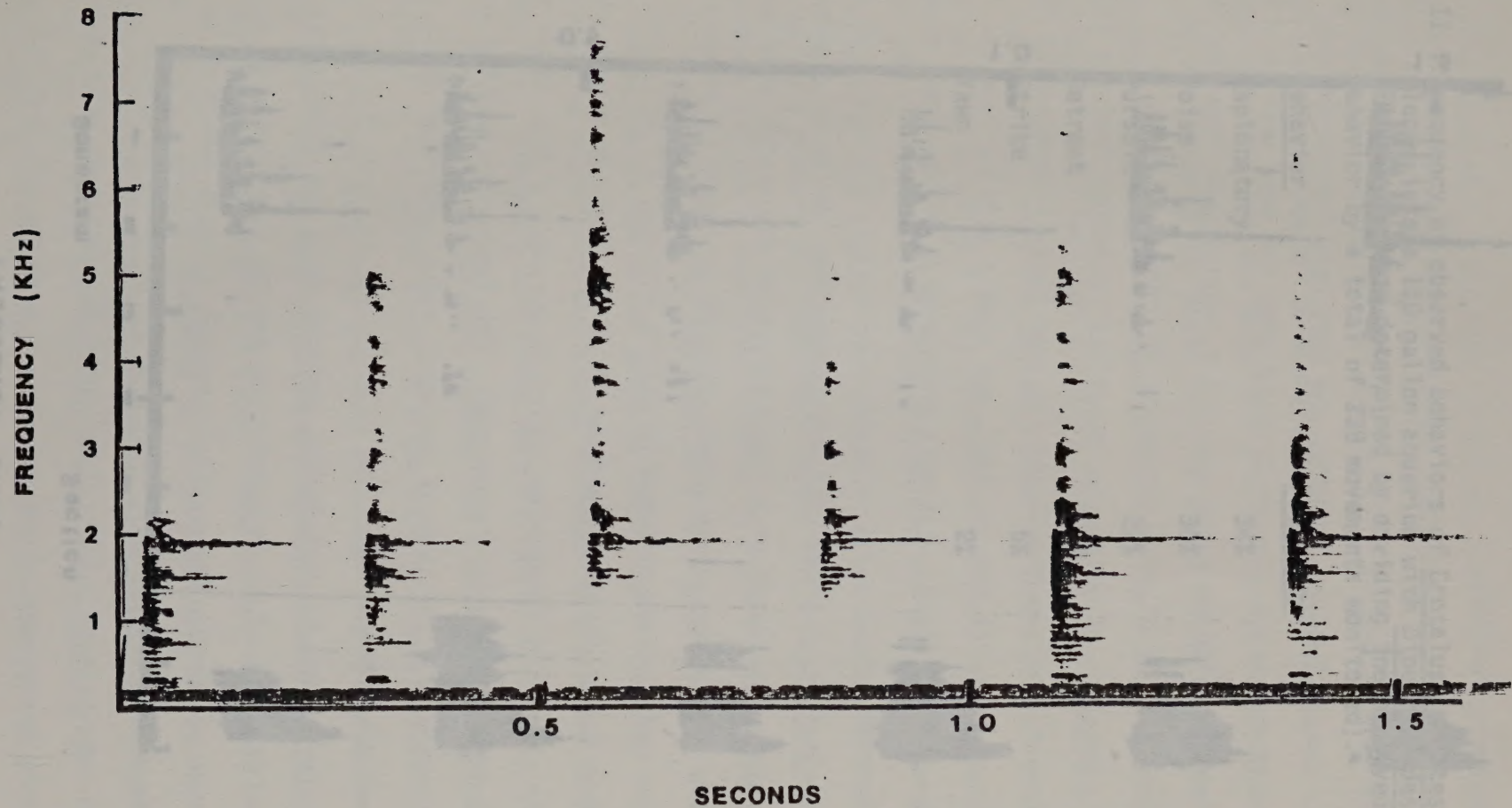


Figure 4: Sonagram of Desert Kangaroo Rat "thumping" hind foot at 10 cm.

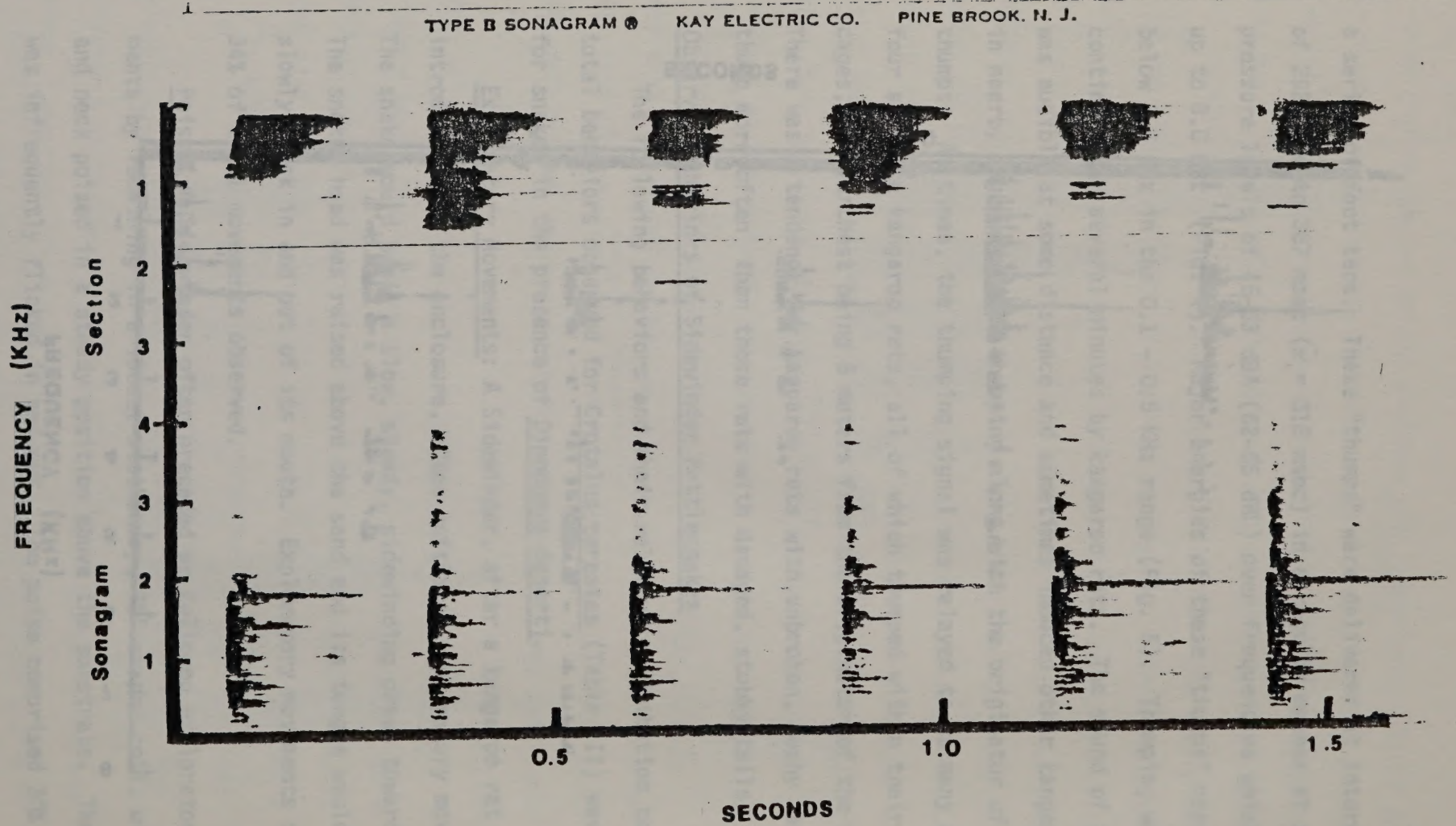


Figure 5: Sonagram and Section of Desert Kangaroo Rat "thumping" hind foot at 10 cm.

Table II Frequency of observed behaviors of Crotalus cerastes placed into a 110 gallon aquarium with Dipodomys deserti. (Each percentage determined by dividing the observed behavior by a total of 238 movements monitored).

<u>Behavior</u>	<u>Frequency</u>
Exploratory	34%
Poise	30%
Pursuit	22%
Retreat	7%
Strike	5%
Yawn	2%

movements observed.

Pursuit: A Sidewinder sometimes actively pursued a rat after an initial contact. A snake would rapidly crawl toward the rat, with its tongue flicking rapidly, and head held toward the rat. When close enough to strike, the snake would draw its head back in a lateral movement, with neck and head nearly equidistant from the rat. Pursuits comprised 22% of total movements observed.

Retreat: A Sidewinder sometimes retreated from the vicinity of a sand kicking rat by pulling its head back, interspersing its body between the rat and its head, and slowly turning from the rat, would slowly crawl away. Retreats comprised 7% of the total movements observed.

Strike: A Sidewinder would sometimes strike at a kangaroo rat. A strike consisted of a rapid thrust of the snake's head toward the rat. While the strike often appeared successful, invariably, the rat would escape unharmed by having executed a nearly simultaneous back leap. Strikes comprised 5% of the total movements observed.

Yawn: A Sidewinder, prior to pursuing a rat, would sometimes extend its jaws in a wide yawn. The fangs were erected and this posture held for several seconds. Yawns comprised 2% of the total movements observed.

Interactions Between Desert Kangaroo Rats and Sidewinders

A total of 87 encounters between D. deserti and C. cerastes were observed. The typical response of each animal to an encounter is described below.

D. deserti: When placed into the enclosure that contained a live Sidewinder at the far end, a kangaroo rat invariably assumed a cautious stance and maintained this posture for several seconds,

up to five minutes. A rat then cautiously explored its immediate vicinity and eventually moved throughout the rest of the enclosure. During this time, a rat would intermittently groom, sand slide, forage, and pause frequently to assume a cautious stance.

When a Sidewinder was detected, a kangaroo rat oriented its head and body toward the snake in a series of quick, sporadic movements and would then advance to contact the snake. During this phase, a rat's head was elevated about 20° above the substrate, with eyes opened, ears and whiskers erected forward, with much sniffing and twitching of the whiskers displayed. Within 10-50 centimeters of the snake, a kangaroo rat turned and accurately kicked sand at the head of the snake. This behavior often caused the snake to relinquish a pursuit and sometimes forced the snake to retreat. A kangaroo rat would sometimes advance to within several centimeters of the snake, sniff, turn and kick sand once again at the snake. Only infrequently did a rat actually touch the snake with its whiskers, an event that was always followed by a violent back leap of the rat. Repeated sand kicks were delivered after this movement.

A kangaroo rat sometimes thumped the substrate after these encounters. A rat would stand in a cautious stance a safe distance from the snake, with head and body directed toward the snake and would shift its balance occasionally, while producing a series of thumps for 3-15 seconds at a time. Thumping was often followed by sand kicks, sideward movements to a new position, or an advance to within a few centimeters of the snake with subsequent reengagement. In the new position, the rat would again kick sand, resume thumping, or reassume a cautious stance, always with its head and body toward

the snake.

C. cerastes: A Sidewinder's response to the introduction of a kangaroo rat into the enclosure was sometimes active, sometimes passive. A snake would initiate exploratory movements which sometimes resulted in contacting a rat. Once contact was made, the snake often assumed a poised posture, apparently examining the rat from a distance. Depending on the behavior of the rat (advance to contact, retreat, etc.) the snake would either remain in this position, engage in pursuit, continue exploration around the rat, strike at the rat, or retreat from the rat.

Most of the 87 encounters observed between Desert Kangaroo Rats and Sidewinders were initiated by the kangaroo rats (61%). The primary response of kangaroo rats to these encounters usually involved a good deal of sand kicking by the rats. A Sidewinder would remain in a poised position during these encounters 53% of the time, retreat from encounters 17% of the time, and strike out at rats 11% of the time. Usually, aggressive, sand kicking kangaroo rats were able to deter further pursuits by the snake. Those kangaroo rats that did not sand kick, or that sand kicked sporadically with little accuracy were often scrutinized more closely, and subjected to more active pursuit by the Sidewinder. For the purposes of the behavioral hearing experiment, only those rats that delivered accurate, repeated sand kicks during 100% of the encounters with the snake were tested.

Relative Effectiveness of Desert Kangaroo Rat Sensory Capabilities

Desert Kangaroo Rats were observed to employ their individual special senses with varying degrees of effectiveness in detecting the presence of a snake (Fig. 6).

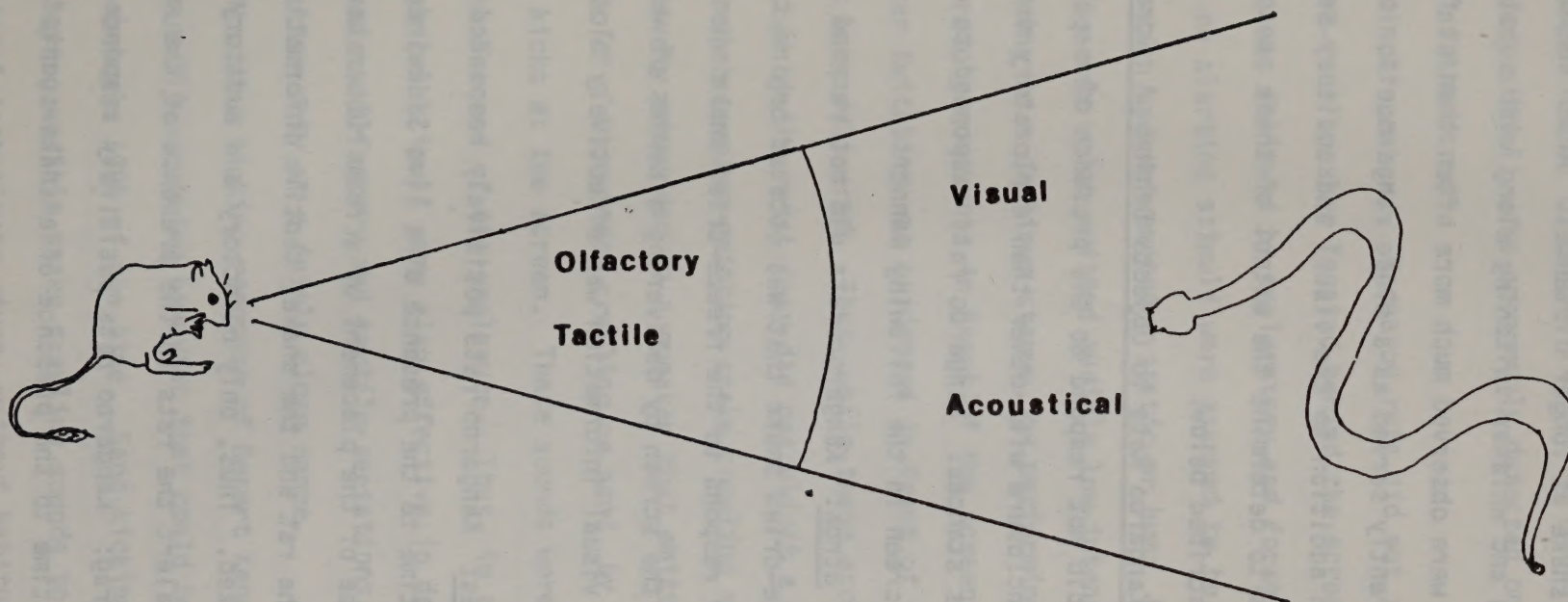


Figure 6: Diagram depicting the relative effective operating ranges of the special sensory systems of *Dipodomys deserti*.

Visual and acoustical stimuli initially alerted the kangaroo rats to the presence of the snake and allowed the rats to monitor the progress of the snake at longer distances. After an advance to contact, sniffing and whisker twitching along with substrate touching activities were observed much more often than at farther distances, and apparently served as a close range monitor of the snake activities, in addition to the visual and auditory senses. Further observations to determine the extent of these sensory capabilities are described below.

Behavior of Desert Kangaroo Rats to Objects Behind A Screen

Two D. deserti did not respond to the presence of a partitioning screen within the enclosure with other than exploratory movements and several cautious stances. Kangaroo rats responded to objects placed behind the screen in the following manners.

Freeze-dried C. atrox: Kangaroo rats did not respond to the presence of a freeze-dried snake that was located behind the screen. They did positively respond to the freeze-dried snake when it was placed in front of the screen by delivering a series of well-placed sand kicks. Thus, visual information was effectively blocked by the screen.

Live C. cerastes: Kangaroo rats positively responded with sand kicks 100% of the time to the presence of a live Sidewinder behind the screen. Because of the placement of a foam rubber barrier in the sand between the rat and the snake, tactile information was assumed to be blocked. Thus, only olfactory and auditory stimuli were available to alert the rats to the presence of the snake.

Snake-scented rag: Kangaroo rats positively responded with sand kicks 100% of the time to the presence of a snake-scented rag placed behind the screen. Rats, however, had to be quite close to the screen

before the snake-scented rag was detected, and then only after several episodes of sniffing. A similar sterile rag, placed behind the screen failed to elicit a positive response from the rats. Thus, olfactory stimuli were apparently detected only a short distance in front of the screen.

8-inch speaker: Kangaroo rats did not respond to the presence of an 8-inch speaker located behind the screen. An initial cautious stance was followed by exploratory and foraging behaviors by both rats. Thus, no alerting stimuli were assumed to be emitted by the speaker.

8-inch speaker emitting static or hum: Kangaroo rats responded to a speaker which emitted audible low-intensity static or hums by remaining in a cautious stance, or performing a series of repeated exploratory movements in front of the screen. Much sniffing and whisker twitching was evidenced in front of the screen, but no sand kicks were delivered. Thus, while these acoustical stimuli were detected by the rats, they did not elicit a sand kicking response.

8-inch speaker emitting snake crawling sounds: Kangaroo rats positively responded to a speaker that emitted audible low-intensity sounds of a Sidewinder crawling on sand, by repeatedly delivering sand kicks at the screen. These sounds were often detected by rats at the far end of the enclosure. Thus, in addition to visual sensations, acoustical stimuli were also effective in detecting intruders at a distance. Olfactory and tactile sensations, however, were apparently effective only at a fairly close range.

The sand kicking response of Desert Kangaroo Rats was, therefore, a naturally-occurring behavior that could be elicited in the selected test animals 100% of the time. Sand kicking could be elicited simply by playing audible snake crawling sounds to rats, and their response would consistently be given, without habituation. Often, the sand

kicking would be continued for several minutes after the snake crawling sounds were terminated. Snake crawling sounds, therefore, provided an excellent auditory cue for use in determining the behavioral hearing thresholds of D. deserti because they elicited an easily observed, preformed, stereotypic behavior that was a direct response to the detection of the specific cue.

Analysis of Sidewinder Crawling Sounds

A Sidewinder crawling at a slow speed on sand at 10 centimeters produced sounds with energies extending from 0.085 KHz - 7.0 KHz (Fig. 7). Major energies were mainly concentrated below 1.4 KHz (especially below 1.0 KHz) but also occurred at around 2.0 KHz (Fig. 8). These sounds were audible at some distance from the snake, but their intensities attenuated rapidly with increased range. (Fig. 9). Within the enclosure, highest sound pressure levels of the snake crawl were monitored directly above the snake. (40-45 dBA, 67-72 dBL). These intensities dropped to 38-40 dBA (65-66 dBL) at 5 centimeters, 36-38 dBA (64-65 dBL) at 10 centimeters, 35-36 dBA (63-64 dBL) at 20 centimeters, 34-35 dBA (62-63 dBL) at 30 centimeters, and fell below ambient sound pressure levels at 40 centimeters (34 dBA, 62 dBL).

These data demonstrate the importance of the auditory sense to kangaroo rats and its role in allowing the kangaroo rats to effectively detect the presence of potential predators at a sufficient distance. This margin of safety allows the rats to engage in activities in response to the predator, thereby increasing their warning and reaction times. The hearing acuities of the Desert Kangaroo Rats tested in this study are described below.

Behavioral Hearing Tests on Desert Kangaroo Rats

The two D. deserti that positively responded to the presence of a live C. cerastes and freeze-dried C. atrox with sand kicks 100% of the

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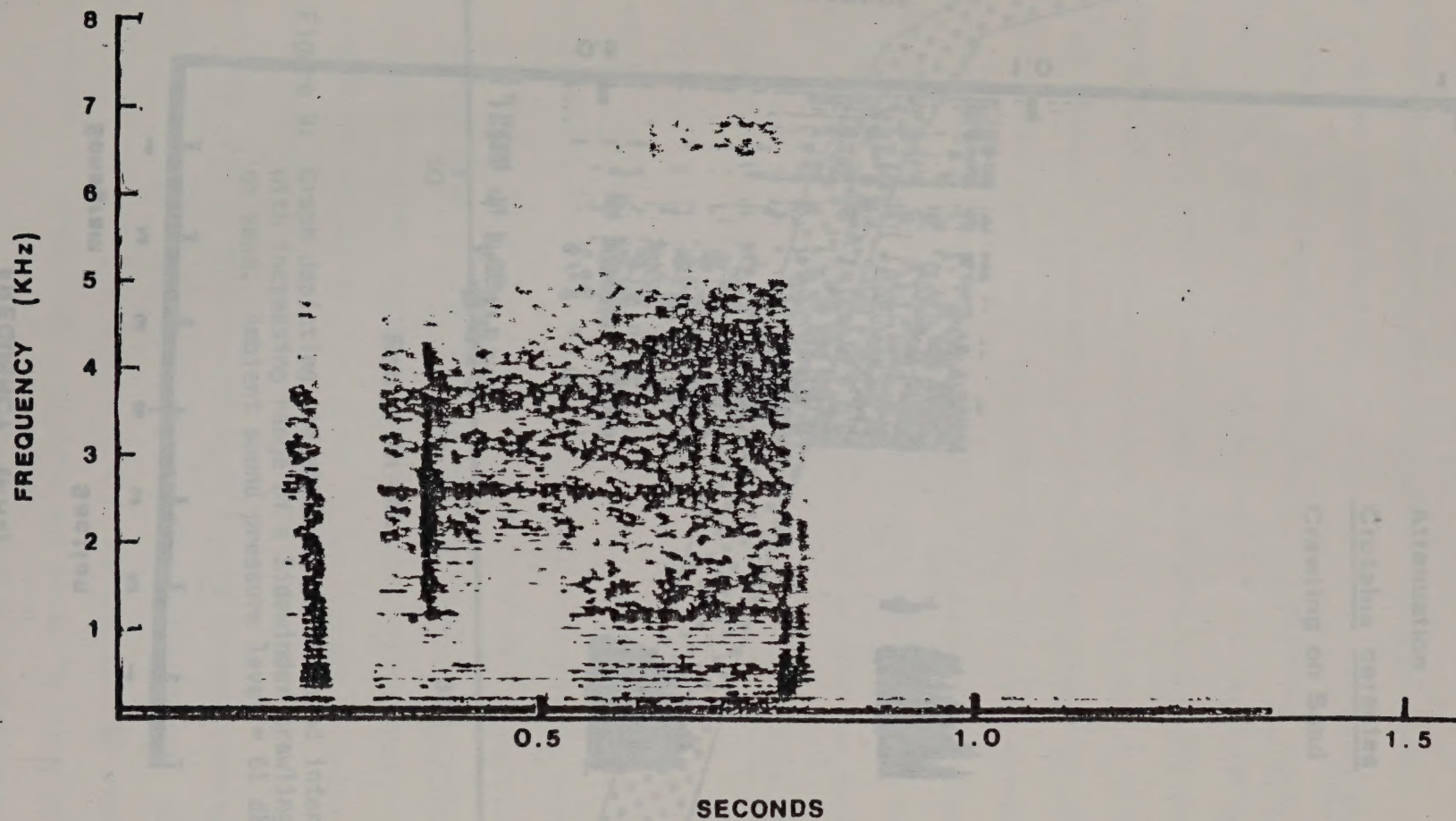


Figure 7: Sonagram of Sidewinder crawling on sand at 10 cm.

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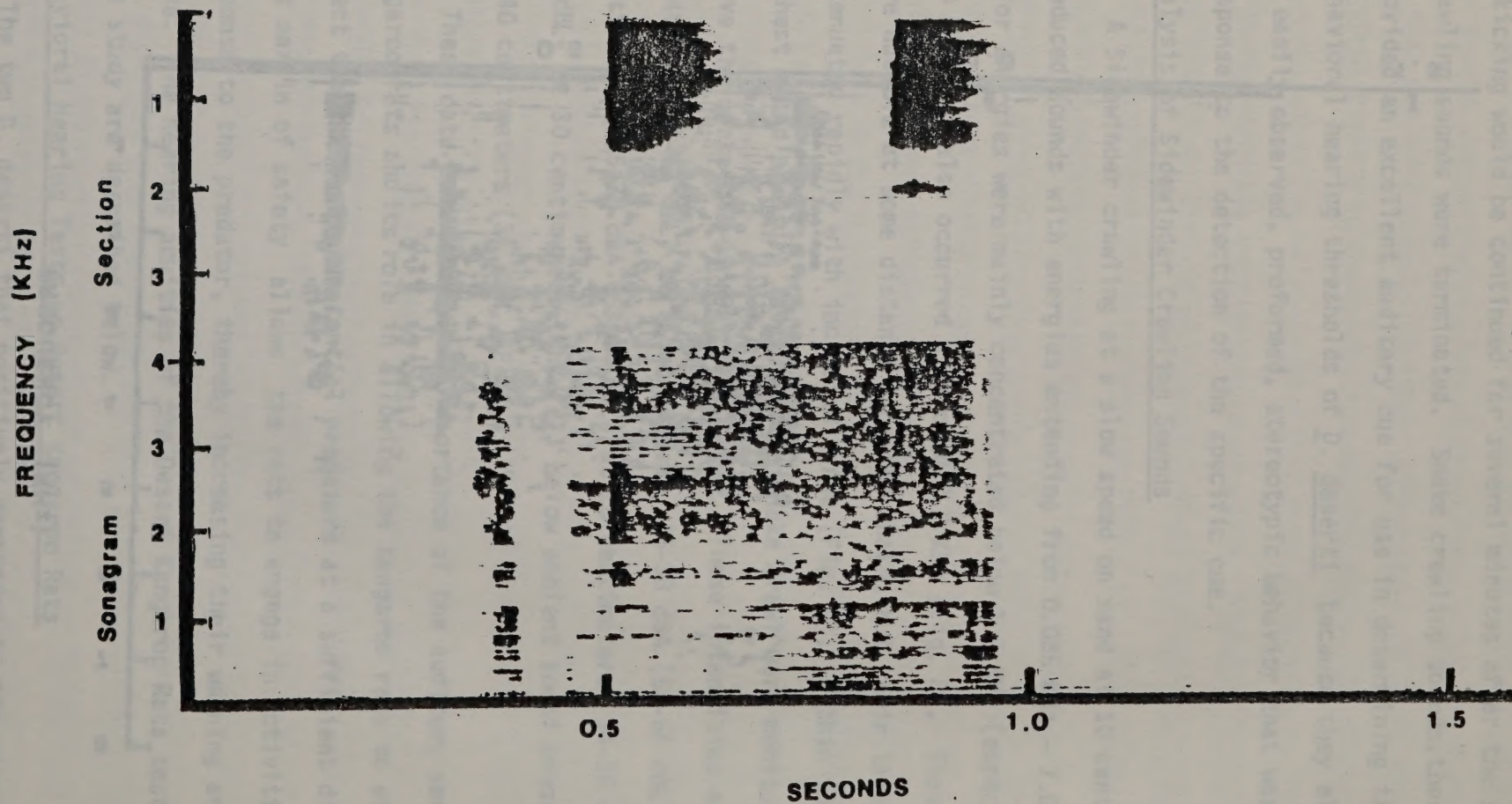


Figure 8: Sonagram and Section of Sidewinder crawling at 10 cm.

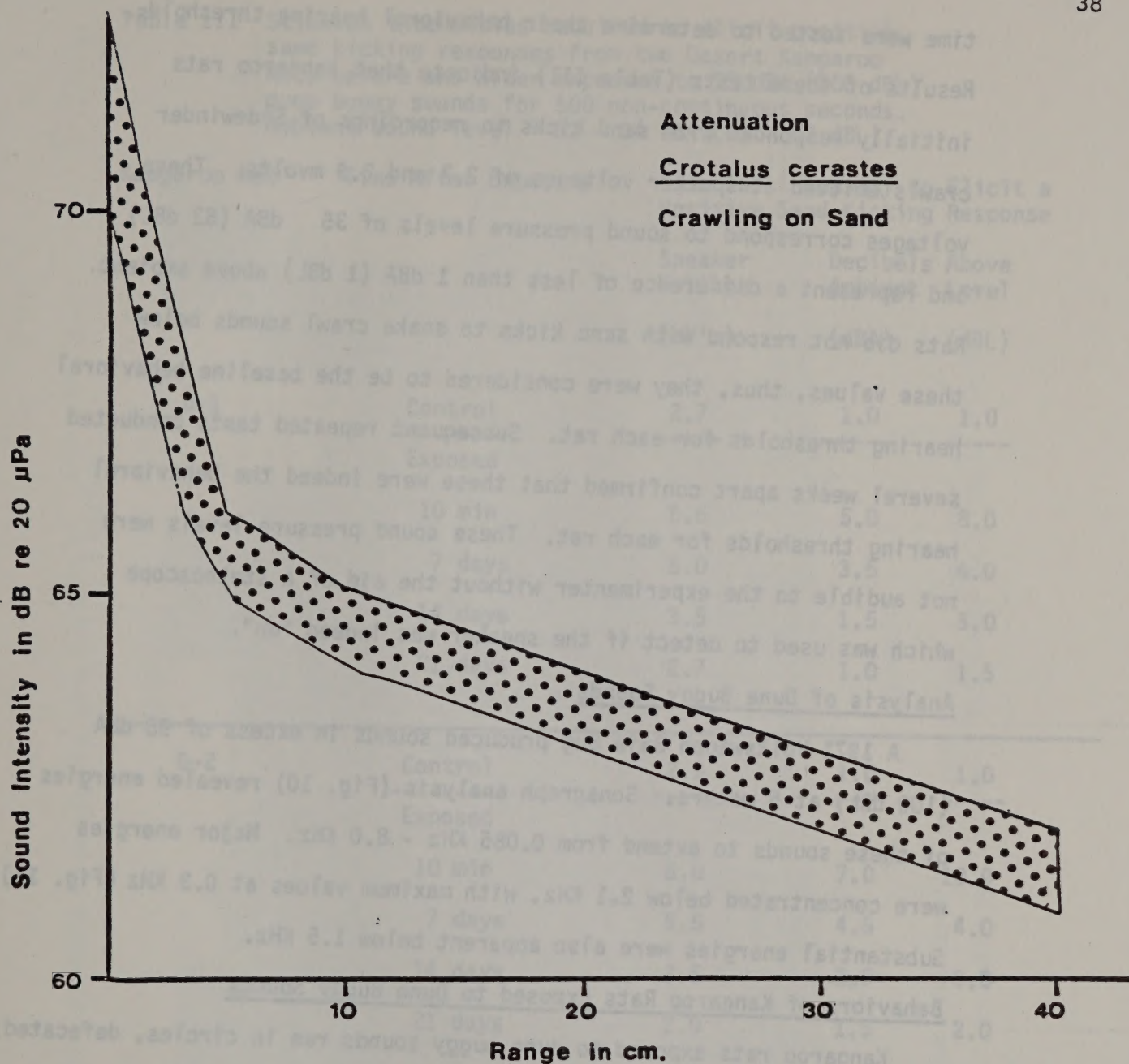


Figure 9: Graph depicting the attenuation of sound intensity with increasing range of a Sidewinder crawling on sand. Ambient sound pressure level = 61 dBL.

time were tested to determine their behavioral hearing thresholds. Results of these tests (Table III) indicate that kangaroo rats initially responded with sand kicks to recordings of Sidewinder crawls emitted at speaker voltages of 2.7 and 2.9 mvolts. These voltages correspond to sound pressure levels of 35 dBA (63 dBL) and represent a difference of less than 1 dBA (1 dBL) above ambient. Rats did not respond with sand kicks to snake crawl sounds below these values, thus, they were considered to be the baseline behavioral hearing thresholds for each rat. Subsequent repeated tests conducted several weeks apart confirmed that these were indeed the behavioral hearing thresholds for each rat. These sound pressure levels were not audible to the experimenter without the aid of a stethoscope which was used to detect if the speaker was indeed "on".

Analysis of Dune Buggy Sounds

A 1971 Volkswagen Baja Bug produced sounds in excess of 95 dBA (100 dBL) at 5 meters. Sonograph analysis (Fig. 10) revealed energies of these sounds to extend from 0.085 KHz - 8.0 KHz. Major energies were concentrated below 2.1 KHz, with maximum values at 0.3 KHz (Fig. 11). Substantial energies were also apparent below 1.5 KHz.

Behaviors of Kangaroo Rats Exposed to Dune Buggy Sounds

Kangaroo rats exposed to dune buggy sounds ran in circles, defecated, pushed at the opening of their cage, chewed on the wooden struts of their cage, started at each new sequence of recorded sounds, frantically groomed themselves and performed repeated slides, and finally shivered on hindlimbs below the speaker, with head lowered. After the sounds were terminated, the rats assumed a cautious stance with heads raised to about 20° above the substrate. No external or middle ear damages were found in either exposed rat.

Table III Stimulus intensities required to elicit positive sand kicking responses from two Desert Kangaroo Rats before and after exposure to 95 dBA (100 dBL) dune buggy sounds for 500 non-continuous seconds. Ambient sound level = 32 - 34 dBA (61 - 62 dBL).

Kangaroo Rat	Time After Exposure	Stimulus Intensity to Elicit a Positive Sand Kicking Response		
		Speaker Voltage (mV's)	Decibels Above Ambient (dBA)	Decibels Above Level (dBL)
D-1	Control	2.7	1.0	1.0
	Exposed			
	10 min	5.5	5.0	8.0
	7 days	5.0	3.5	4.0
	14 days	3.5	1.5	3.0
	21 days	2.7	1.0	1.5
D-2	Control	2.9	1.0	1.0
	Exposed			
	10 min	8.0	7.0	10.0
	7 days	5.5	4.5	4.0
	14 days	3.5	2.0	3.0
	21 days	2.9	1.5	2.0

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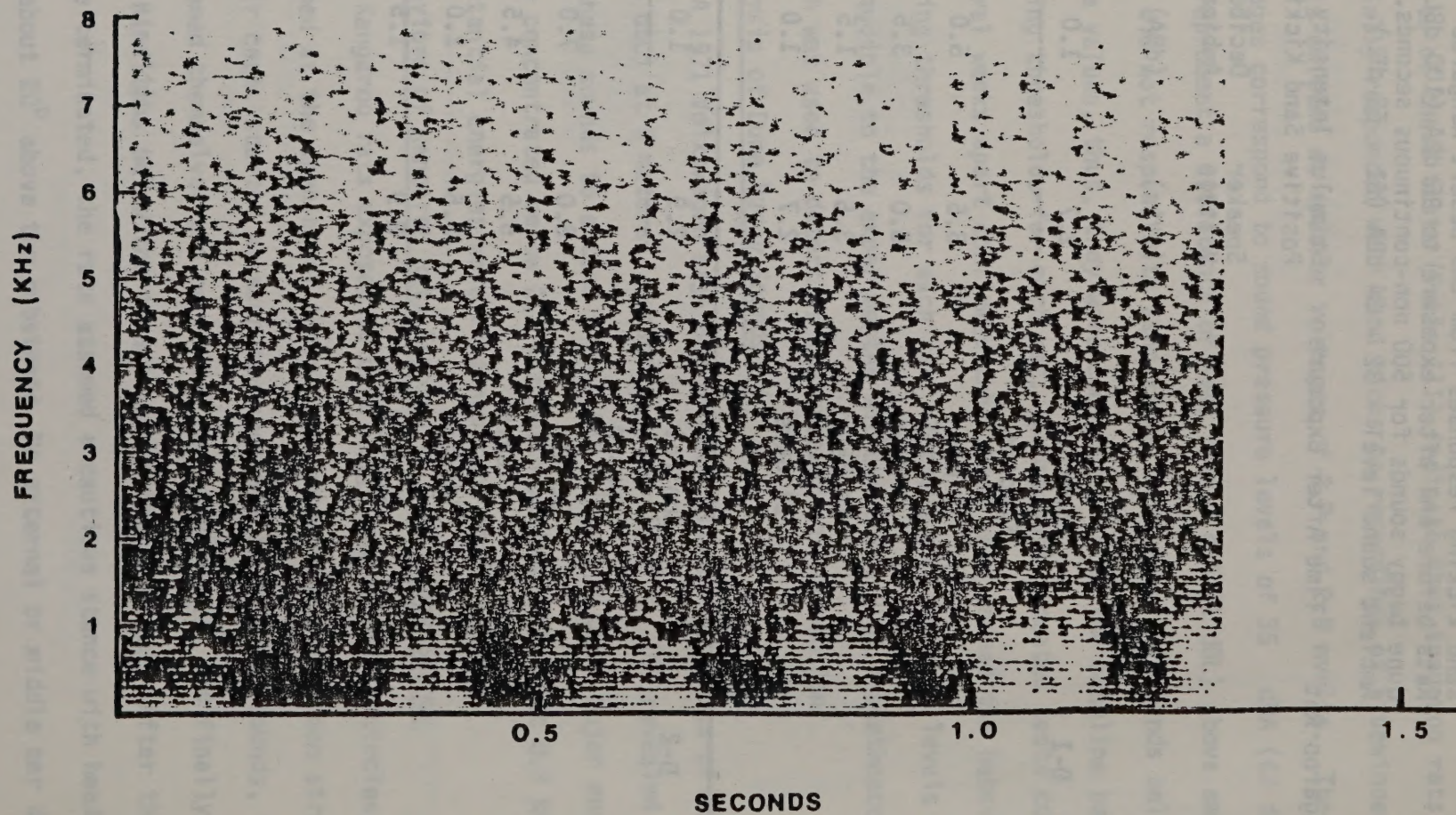


Figure 10: Sonagram of Volkswagen Baja Bug at 5 meters.

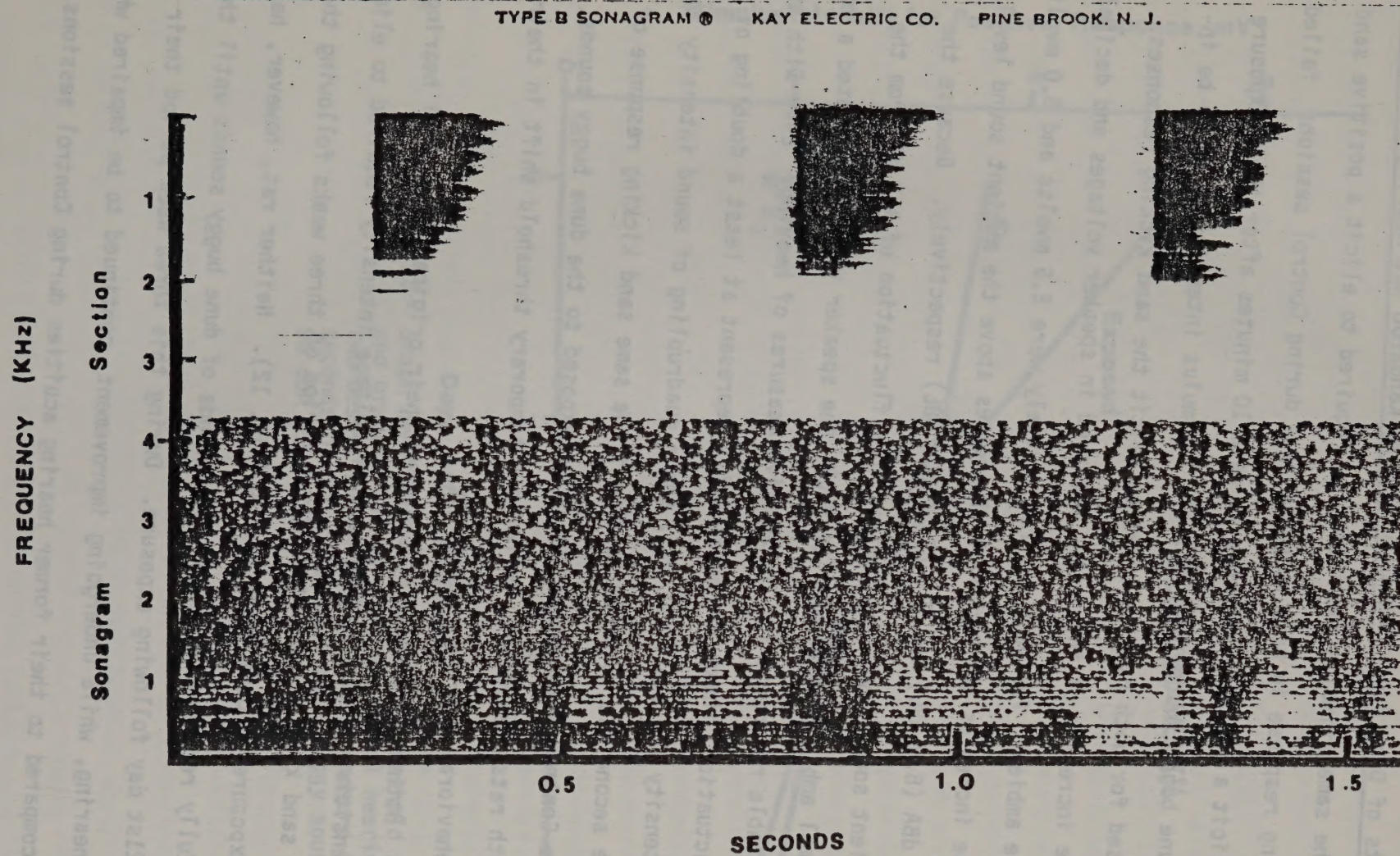


Figure 11: Sonagram and Section of Volkswagen Baja Bug at 5 meters.

Effects of Dune Buggy Sounds on Desert Kangaroo Rat Hearing Thresholds

The same stimulus and intensity required to elicit a positive sand kicking response in both kangaroo rats during Control sessions failed to elicit a positive response in rats 10 minutes after their exposure to dune buggy sounds (Table III). Stimulus intensities had to be increased for both rats in order to elicit the sand kicking responses. These increases of intensity, measured in speaker voltages and decibels above ambient, for each rat respectively were 5.5 mvolts and 8.0 mvolts. These increases correspond to increases above the ambient sound levels of 5.0 dBA (8.0 dBL) and 7.0 dBA (10.0 dBL) respectively. Because the ambient sound level was subject to a fluctuation of ± 1 dB from the normal ambient of 33 dBA (61 dBL), the speaker voltage presented a more reliable reference for comparative measures of hearing. Even with this fluctuation, these increases still represent at least a doubling of intensity for the first rat, and a quadrupling of sound intensity for the second rat in order to elicit the same sand kicking response of the Control sessions after being exposed to the dune buggy sounds. Both rats, therefore, suffered a temporary threshold shift in their behavioral hearing sensitivity.

Both rats gradually recovered their original behavioral hearing sensitivity, measured by speaker voltage intensity required to elicit a sand kicking response, over a period of three weeks following their exposure to dune buggy sounds (Fig. 12). Neither rat, however, had fully recovered from the 500 seconds of dune buggy sounds until the 21st day following exposure. During this three week period their hearing, while undergoing improvement, continued to be impaired when compared to their former hearing acuities during Control sessions.

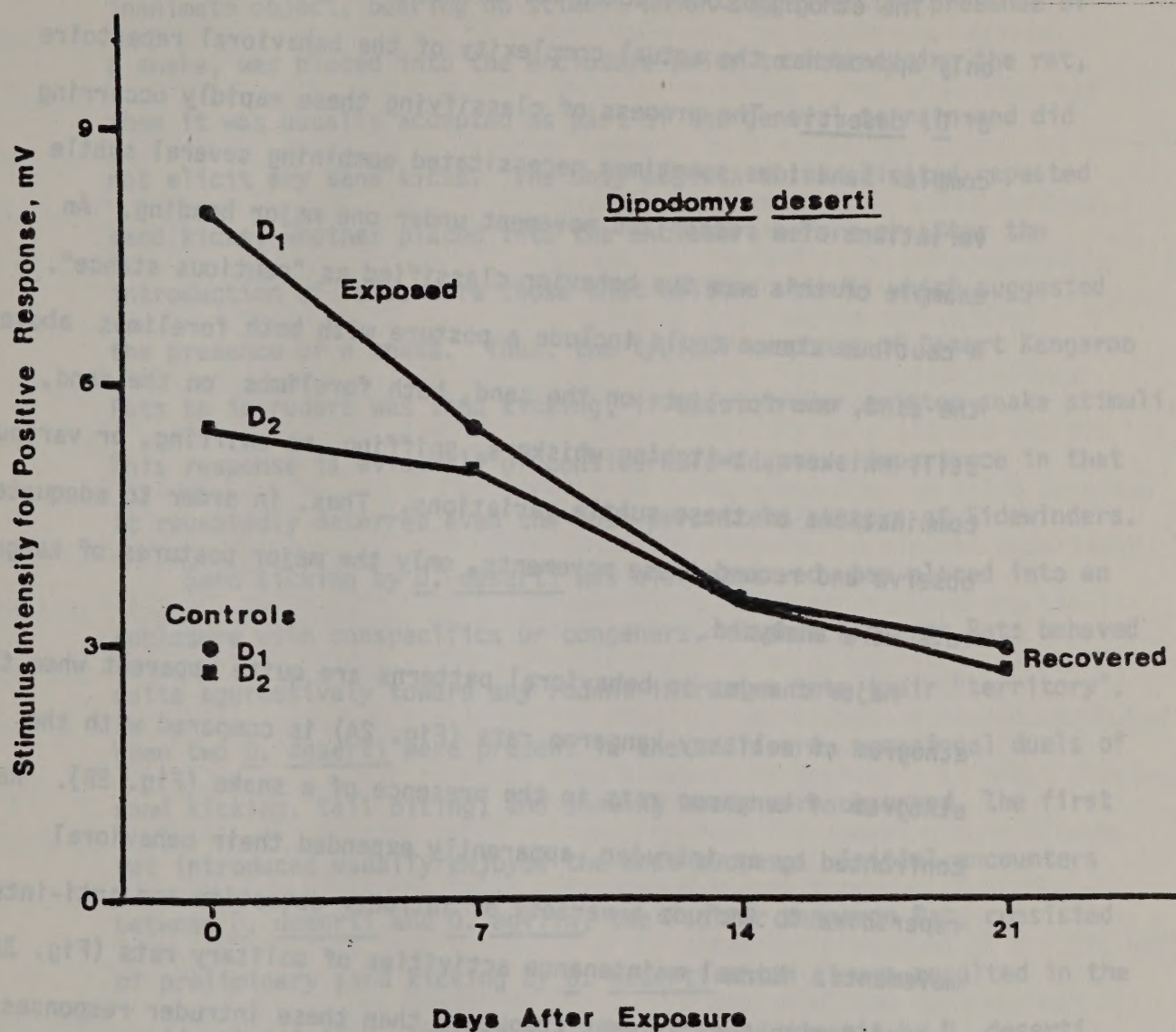


Figure 12: Graph depicting the temporary threshold shift and gradual recovery of behavioral hearing in two Desert Kangaroo Rats after exposure to 500 seconds of non-continuous dune buggy sounds of 95 dBA (100 dBL).

DISCUSSION

The ethogram constructed for solitary kangaroo rats (Fig. 2A) only approaches the actual complexity of the behavioral repertoire of D. deserti. The process of classifying these rapidly occurring complex behaviors sometimes necessitated combining several subtle variations of a recognized movement under one major heading. An example of this was the behavior classified as "cautious stance". A cautious stance could include a posture with both forelimbs above the sand, one forelimb on the sand, both forelimbs on the sand, still whiskers, twitching whiskers, sniffing, no sniffing, or various combinations of these subtle variations. Thus, in order to adequately observe and record these movements, only the major postures of kangaroo rats were analyzed.

Major changes in behavioral patterns are quite apparent when the ethogram of solitary kangaroo rats (Fig. 2A) is compared with the ethogram of kangaroo rats in the presence of a snake (Fig. 2B). Rats confronted by an intruder apparently expanded their behavioral repertoire to include a variety of intruder detection and anti-intruder movements. Normal maintenance activities of solitary rats (Fig. 3A) occurred with a much lower frequency than these intruder responses (Fig. 3B). The detection of an intruder, then, is apparently the single factor responsible for initiating these large shifts in the behaviors of Desert Kangaroo Rats.

The anti-intruder behavior of sand-kicking by D. deserti, was first described by Benson (1935), wherein he suggested its possible role in deterring rattlesnake predation. Our observations certainly support this hypothesis, in that Sidewinders never managed to deliver a successful strike during any of the 87 encounters with D. deserti. D. deserti apparently kicked sand at any foreign object which was

introduced after rats were already in the enclosure. However, if an inanimate object, bearing no stimuli which suggested the presence of a snake, was placed into the enclosure prior to introducing the rat, then it was usually accepted as part of the general terrain and did not elicit any sand kicks. The only objects which elicited repeated sand kicks, whether placed into the enclosure before or after the introduction of rats, were those that emitted stimuli which suggested the presence of a snake. Thus, the typical response of Desert Kangaroo Rats to intruders was sand kicking, if the intruder emitted snake stimuli. This response is evidently of considerable adaptive importance in that it repeatedly deterred even the most persistent attacks of Sidewinders.

Sand kicking by D. deserti was also observed when placed into an enclosure with conspecifics or congeners. Desert Kangaroo Rats behaved quite aggressively toward any rodent intrusion into their "territory". When two D. deserti were present in the enclosure, occasional duels of sand kicking, tail biting, and shoving bouts were observed. The first rat introduced usually enjoyed the most success. Initial encounters between D. deserti and D. agilis, the Pacific Kangaroo Rat, consisted of preliminary sand kicking by D. deserti which always resulted in the rapid retreat of D. agilis, and equally rapid pursuit by D. deserti. Similar dominance of D. deserti over D. merriami has been reported by Congdon (1974). Desert Kangaroo Rats, then, apparently employed sand kicking in a variety of contexts, which ranged from predator-prey interactions to intra- and interspecific territorial defense. Sand kicking by D. agilis was not observed, nor has it been seen in D. merriami by previous workers (Webster and Webster, 1972).

D. deserti is considered to be the most specialized kangaroo rat by most workers (Grinnell, 1922; Wood, 1935; Lidicker, 1960; and Nader, 1978). This specialization is reflected by its extremely

narrow habitat requirements. Desert Kangaroo Rats are stenoecious and occur only where they can dig their burrows in wind blown sand (Ingles, 1965). D. merriami also showed a preference for sandy soils (Lidicker, 1960), but have apparently been excluded from sand dunes by the more dominant D. deserti and, therefore, radiated into less preferred habitats (Congdon, 1974). Thus, the restriction of D. deserti to the unique habitat of desert sand dunes and their successful defense of this territory against congeners has resulted in the situation that only Desert Kangaroo Rats occur on loose sand, while other kangaroo rats occupy more compacted soil regions. This trend most likely explains how D. deserti has come to develop the kicking of loose sand as an anti-intruder behavior, while other species of kangaroo rats have not.

The reliability of the sand kicking response, as a signal to the observer that a Desert Kangaroo Rat has detected an intruder was repeatedly confirmed during this experiment. Regardless of the duration or number of times a specific "snake" stimulus was presented, selected D. deserti consistently responded with sand kicks and never habituated to the stimuli. The sand kick was, therefore, very useful as a criterion for determining the behavioral hearing thresholds of D. deserti.

The hearing ability of D. deserti was remarkably keen. Sand kicking responses were frequently elicited by auditory stimuli emitted from a speaker at a range beyond 50 centimeters. These same stimuli were often inaudible to the observer without the aid of a stethoscope held close to the speaker. Both rats were able to detect the low-intensity sounds of a Sidewinder crawling at ranges well over 40 centimeters. Thus, the adaptive importance of acute hearing to kangaroo rats can not be too highly stressed.

Predators of kangaroo rats have adapted equally remarkable means of detecting prey in total darkness. Webster (1962) reports the abilities

of Screech Owls, Otus asio, through means of acoustical localization, and Sidewinders, by means of infrared sensation, to locate and capture hearing-impaired kangaroo rats in total darkness. Yet, also reported were the abilities of unimpaired kangaroo rats to evade capture, by acoustically detecting the approach of the predators in total darkness. Both the "silent" flight of owls, and the "quiet" crawl of Sidewinders emitted low-intensity acoustical energies well within the optimal hearing ranges of D. merriami, 1.0 - 3.0 KHz. These predator sounds were very faint and ranged up to 1.2 KHz for the owls and 2.0 KHz for the Sidewinders, but the kangaroo rats exceptional hearing still detected their presence and allowed them to escape capture. A similar experiment conducted under more controlled conditions (Webster and Webster, 1971) for longer durations yielded similar results for D. merriami. Thus, kangaroo rat hearing abilities represent a specialization that contributes immeasurably to their survival when attacked by predators in total darkness.

The optimal hearing sensitivities reported for kangaroo rats between 1.0 - 3.0 KHz (Webster, 1962) coincided with the frequencies of the lowest fundamental tone for calls of 17 passerine predators ($\bar{x}$ = 1.225 KHz) and 16 non-passerine predators ($\bar{x}$ = 1.537 KHz) analyzed by sonograph (Patterson, 1971). Canid digging and sniffing sounds also occurred at these frequencies between 1.0 - 3.0 KHz (Campbell, 1969). The ability of Desert Kangaroo Rats to successfully avoid predation by Kit Foxes, Vulpes macrotis, owls and snakes has been suggested by Nader (1978), due to the scarcity of records of known predators on D. deserti. Thus, a well-maintained, acute sense of hearing is of high adaptive importance to kangaroo rats in that it allows them to detect and continuously monitor predators in total darkness, and apparently, to successfully escape their attacks. Acute hearing, therefore, warns healthy kangaroo rats of predator approach and enables them to escape capture, and in the cases of D. deserti

ensures the prompt delivery of proper anti-intruder responses.

Thumping after encounters with intruders may simply be displacement activity. Evidence for this is that thumping has also been reported for D. deserti immediately after sexual encounters, as have sand kicks, presumably signaling a high state of excitement (Butterworth, 1961).

Other hypothetical functions of thumping may be as signals to conspecifics, or the transmission and reception of acoustical or tactile information through the desert air or sand. Tactile information may be of special importance to kangaroo rats in detecting objects (i. e. half-submerged Sidewinders) at relatively close distances in the sandy substrate. Thumps possessed sufficient regularity and frequency compositions (Fig. 4) with major energies at proper frequencies (Fig. 5) to be carried for a distance. Also, the reception and relay of thumping signals between as many as four conspecifics certainly suggests that roles other than displacement activity may be involved. These hypotheses warrant further investigation.

Evidence that kangaroo rats were less active during portions of nights with lunar illumination is provided by Lockard and Owings (1974). Their studies with Bannertail Kangaroo Rats, D. spectabilis, indicated that kangaroo rats avoided moonlight, possibly as a means of lowering their losses to visually hunting predators. Degrees of moonlight avoidance were shown to vary seasonally. Kangaroo rats avoided moonlight much more during the longer nights (13 hours) of late Fall, than during the shorter nights (9 hours) of late Spring. Possible explanations for this seasonal shift are complex and consider available foraging time, temperature, food availability, cache sizes (Lockard and Owings, 1974) in addition to cost or profit versus exposure computations (Rosenzweig, 1974). These explanations need not be elaborated, suffice to say that kangaroo rats are apparently more active when lunar illumination is absent. Hence,

kangaroo rats are most active when the moon is down and it is during this time that they rely most heavily on their auditory capabilities for predator detection and avoidance.

The immediate effects of dune buggy sounds on the behavioral hearing of both Desert Kangaroo Rats tested was to lower their hearing sensitivities and thereby raise their hearing thresholds by 4 dBL in one subject and 9 dBL in the other (Fig. 12). This means that the actual power intensity of the stimulus had to be increased by two times in the first subject, and eight times for the second, over what it had previously been in order to elicit the same response in these individuals. Expressed another way, these required increases in stimulus intensities represent decreases in the effective audible detection distance between the rats and the sound source previously observed in Control sessions (40 centimeters + for each individual). Ten minutes after sound exposure, this warning distance dropped to less than 2 centimeters (Fig. 9).

Recovery from sound exposure thus gradually restored the effective warning distance, previously seen in Controls. Seven days after exposure warning distances increased to at most 12 centimeters, after 14 days to a maximum of 21 centimeters, and the original warning distance (40 centimeters) was not achieved until 21 days after the sound exposures.

The normal striking distance of rattlesnakes have generally been reported as being between $1/3$ to $1/2$ of the total body length of the specific reptile, though some have been known to exceed this distance (Klauber, 1956). The Sidewinder recorded in this experiment was 48 centimeters in total length (45 centimeters in snout-vent length). This snake would therefore be expected to have a normal striking range of between 16 - 24 centimeters. Thus, for nearly 21 days following the sound exposure, under darkened conditions, both rats could conceivably have been approached, monitored, and successfully struck by this

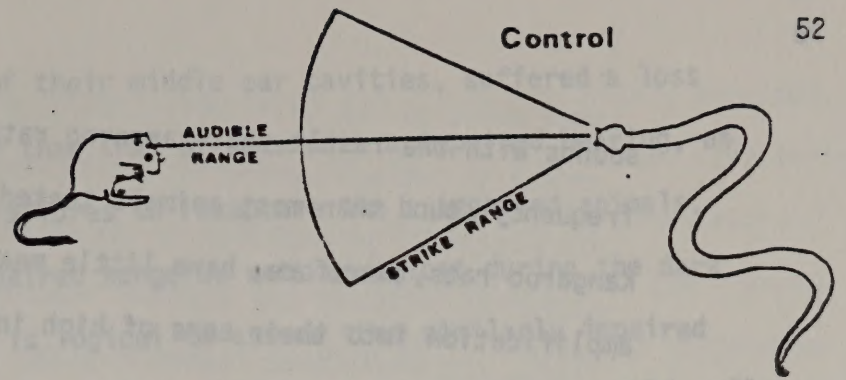
Sidewinder, without having received detectable acoustical warning (Fig. 13).

Dune buggy sounds of 95 dBA (100 dBL) delivered in a non-continuous duration of 500 seconds, therefore, seriously impaired the behavioral hearing of D. deserti and deprived these animals of their primary dark-adapted predator detection senses. Thus, the dune buggy sounds immediately lowered the fitness of both kangaroo rats by removing their primary ability to detect the approach of predators in the dark for up to 21 days after their exposures.

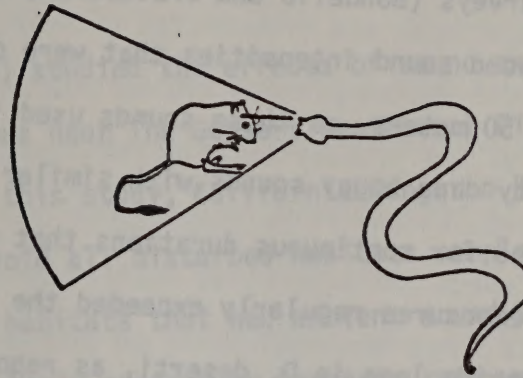
Characteristics of the dune buggy sounds which contributed to the destruction of hearing and predator detection in kangaroo rats included their high sound intensities and the frequency components of their major sound energies. Sonagraph analysis indicated that major energies of the high intensity sounds were carried beyond 6.0 KHz (Fig. 10) with highest concentrations below 2.0 KHz (Fig. 11). Thus, major sound energies occurred at the region of the most acute hearing sensitivity (1.2 - 1.4 KHz) of kangaroo rats as determined by Webster (1962).

The ears of D. merriami were seen to be overloaded near this region (1.5 KHz) by sound intensities of 20 dB re 1 dyne/centimeter² by Vernon, Herman, and Peterson (1971). This intensity corresponds to the 100 dB re 20 uPa exposure delivered in this study. Kangaroo rat ears may, therefore, be assumed to be quite vulnerable to sounds with high concentrations of energy in the region of 1.0 - 3.0 KHz.

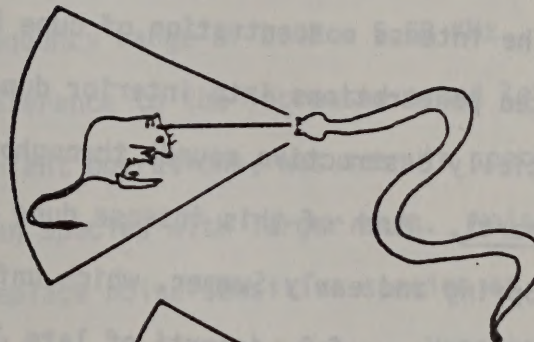
Kangaroo rat ears possess a variety of anatomical adaptations which promote the amplification of low-frequency sounds, presumably because this is the region in which critical environmental sounds (i. e. mammalian, avian, and reptilian predators) are most apparent. These adaptations include their enlarged auditory bullae, high tympanic membrane to stapes footplate transformer ratios, and unimpaired middle ear ossicles (Webster, 1962). All of these structures function to reduce the dampening of low frequency



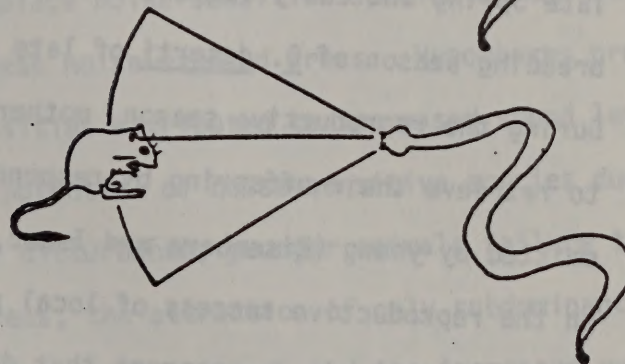
Control



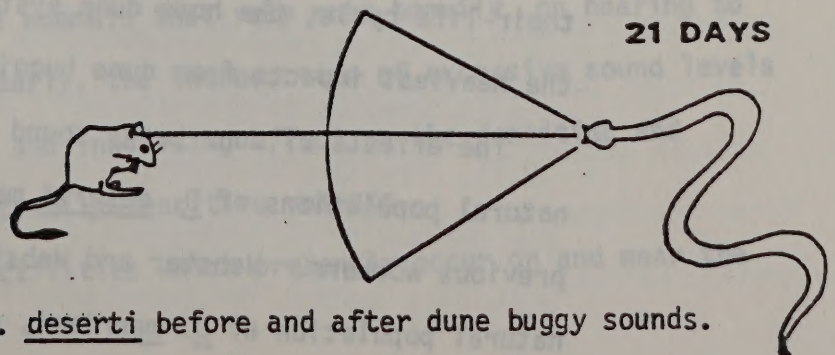
10 Minutes



7 Days



14 DAYS



21 DAYS

Figure 13: Audible range of D. deserti before and after dune buggy sounds.

sounds with the result that kangaroo rats are more sensitive to lower frequency sound than most animals tested (Vernon, Herman, Peterson, 1971). Kangaroo rats, therefore, have little means of preventing the full amplification into their ears of high intensity, low frequency sounds produced by dune buggies.

Field surveys (Bondello and Brattstrom, 1978) found that dune buggies produced sound intensities that were over twice as high (105 dBL) at ranges of 50 meters, as those sounds used in this experiment. Other high intensity dune buggy sounds, with similar acoustical characteristics, were monitored for continuous durations that exceeded five minutes. Thus, field sound exposures regularly exceeded the cumulative dosage required to elicit hearing loss in D. deserti, as reported in this study.

The intense concentration of dune buggies on sand dunes and their repeated penetrations into interior dunes, therefore, repeatedly spreads potentially destructive sounds throughout the restricted habitat of D. deserti. Much of this intense dune buggy activity occurs during late Spring and early Summer, which unfortunately coincides with the breeding season of D. deserti of late January to mid-July (Nader, 1978). During the reproductive season, mothers of infant kangaroo rats are known to retrieve their offspring by responding to repeated scratchy-whines emitted by young (Eisenberg and Isaac, 1963). The effects of ORV penetrations on the reproductive success of local populations of D. deserti is not known, however, it is apparent that during the most critical phase of their life cycle, the home dune systems of Desert Kangaroo Rats receive the heaviest impacts from dune buggies.

The effects of dune buggy sound exposures on the well-being of natural populations of D. deserti may be inferred from the studies of previous workers. Webster and Webster (1971) found that members of a natural population of D. merriami, whose hearing was impaired by surgically

decreasing the volume of their middle ear cavities, suffered a loss rate three times higher than that of rats with unimpaired hearing, as evidenced by repeated failures to recapture the impaired animals. Most of the hearing impaired kangaroo rats were lost during the dark phase of the moon. It is logical to assume that similarly impaired D. deserti, following relatively brief ORV sound exposures, would suffer similar losses.

Hurley (1977) studied the effects of sound exposures on small mammal populations near The Geysers Geothermal Field in northern California. In this study, California Kangaroo Rats, D. californicus, were found to avoid all disturbed habitats sampled, and also avoided all undisturbed habitats that had ambient sound levels in excess of 59 dBL. Particularly avoided by kangaroo rats were areas that exceeded 38 dBL in the mid-frequency range of 1.42 - 5.68 KHz. Among other rodents, a greater tolerance to the increased sound levels, which resulted from power plant operations, was seen in species whose members had smaller ears, than species with larger ears. Noise-tolerant species were also found to replace noise-sensitive species as the dominant species present in these noise-exposed areas. Hypotheses proposed to explain these low densities attributed to increased sound levels included lowered reproductive potential of noise-sensitive species due to physiological or behavioral disturbance, younger animals failure to disperse into sound exposed areas, the attraction of only subdominant animals to the marginal habitats exposed to sound, and the increased vulnerability to predators of small mammals that rely most heavily on hearing to escape predation. Clearly, the introduction of excessive sound levels can have a disturbing and inhibiting effect on the densities and distribution of acoustically-sensitive rodents.

The intense ORV activities which presently occur on and near the

sand dunes of the California Desert, then, clearly constitute a threat to the well-being of Desert Kangaroo Rats and other dune inhabitants. In addition to the increasing number of reports that currently document the physical destruction of the desert geology, flora, and fauna that result from ORV incursion (Webb and Wilshire, 1978) must now be considered the acoustical impacts. Our study suggests that the magnitudes and frequencies of occurrence of ORV sounds in the California Desert present a clear and present danger to the well-being of the natural wildlife of these regions.

Local populations of D. deserti are not likely to simply move away from dunes where ORV activities occur. Because of their narrow habitat requirements, they are restricted to the dune habitat and can not move away from them into less impacted, differently composed regions (i.e. hard pan) which may border the dunes. They are not likely to move successfully into adjacent dune systems either in that their conspecifics already occupy these areas and defend their territories with as much tenacity as all other D. deserti. Local populations of D. deserti, therefore, do not enjoy the option of successfully emigrating away from ORV impacted dunes. The only recourse of these populations of Desert Kangaroo Rats is to attempt to absorb the impacts of ORV's on their dunes.

Intense ORV activities on their home dunes, however, can not be tolerated by D. deserti. Desert Kangaroo Rats are too specialized to tolerate the disturbance to their habitat which would result from ORV activities, much as California Kangaroo Rats could not tolerate the disturbance of habitats near The Geysers Geothermal Field (Hurley, 1977). The same specialized niche requirements which contribute to the success of D. deserti on undisturbed, quiet, productive sand dunes, make this species totally intolerant of disturbances caused by ORV's.

The intolerance of D. deserti to disturbance can not be too highly stressed. Desert Kangaroo Rats construct burrows that are too fragile, defend territories too rigidly, and rely too heavily on unimpaired hearing for survival every night to tolerate even the most cursory of ORV penetrations into their dunes. None of the narrow niche requirements of D. deserti is subject to compromise without seriously jeopardizing the existence of local populations of these animals.

As a major component of the community energy flow and material transport of the dune ecosystems, Desert Kangaroo Rats can not be too highly protected. D. deserti is as specialized as any of the other dune inhabitants. Dune ecosystems are also one of the most unique, specialized, functional, and challenging of all habitats. Survival in this habitat imposes severe constraints on all dune inhabitants, with each day and night representing a constant struggle for survival. The imposition of so destructive a burden as ORV invasion on dune habitats should not, for one moment, be allowed. The impairment of hearing of populations of kangaroo rats, which would apparently result from intense ORV activities, for even a few nights, must also not be allowed. Intact, healthy, undisturbed populations of these uniquely adapted animals must be maintained without alterations of any kind. To attempt to separate the various components of dune habitats (geological, floral, and faunal) into expendable and unexpendable, ORV-tolerant and ORV-intolerant units would be the greatest folly, for to do so would be to invite serious repercussions throughout the entire exposed area.

It is, therefore, the recommendation of this report that ORV activity, and other disturbing activities, be totally excluded from the critical habitat of the sand dunes of the California Desert, that these regions be immediately designated as sensitive areas and that all component parts of this ecosystem be afforded protection from all such disturbing activities

which may occur on or near these areas. Failure to adopt these measures, and the continued abuse of these uniquely adapted, vulnerable habitats, will result in the continued destruction of these irreplaceable natural communities.

CONCLUSION

Behaviors of Desert Kangaroo Rats and the importance of their auditory sense in predator detection and avoidance is described. Dune buggy sounds of 95 dBA (100 dBL) and cumulative exposure of 500 seconds severely impaired kangaroo rat hearing, below levels requisite to warn of potential Sidewinder approach. Recovery occurred within 21 days, during which time kangaroo rats were still unable to detect the approach of Sidewinders within an adequate range of safety. The extreme importance of unimpaired acute hearing of kangaroo rats for predator detection, especially during the darkest nocturnal hours, is described with reference to several supportive laboratory and field studies.

The highly specialized ecology of Desert Kangaroo Rats and their total dependence on undisturbed wind-blown sand habitats are described. Factors contributing to the uniquely quiet acoustical environment of hot, dry desert sand dunes are identified.

Implications of continued abuse of desert sand dune systems by ORV's are made with reference to the inability of indigenous wildlife to withstand mechanized intrusion. Protection of Desert Kangaroo Rats and other threatened dune inhabitants, designation of desert sand dune systems as critical habitat of these inhabitants, and restriction of ORV's from these areas and other fragile desert habitats is strongly advised.

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CONCLUSIONS OF THE FINAL REPORT

The foregoing studies indicate that ORV activities in the California Desert represent disruptive and often destructive influences on the native wildlife of this region. Further, these studies indicate that ORV sound levels of lower intensity and shorter duration than those monitored in the desert can disrupt and destroy essential features of desert wildlife. Detrimental effects of ORV sounds result from the acute sensitivity of desert vertebrates to the reception of specific environmental sounds.

Several factors contribute to processes of natural selection which have made desert vertebrates so sensitive to the reception of specific sounds. The intense heat and dryness which characterizes this region during the most active Spring and Summer months of these animals greatly reduces the effective conduction of sound in this environment (Harris, 1967). Natural constraints of heat and dryness function to rapidly attenuate sounds of higher frequency while lower frequencies are carried for greater distances (Harris, 1967). The result has been that the reception of higher frequency sounds by prey animals implies nearness and often danger (Hardy, 1956). The ability to receive lower frequency sounds (below 3.0 KHz), therefore, benefits animals by extending the range at which important environmental stimuli (predator approach) are audible. (Webster and Webster, 1971). Because critical environmental sounds are often of relatively low intensity (snake crawls and owl swoops) sensitive hearing acuity is essential to the survival of many desert vertebrates. The result of these natural selective forces has been the evolution of many types of desert vertebrates (spadefoot toads, lizards, kangaroo rats) with the ability to hear low intensity, low frequency sounds.

Bondello and Brattstrom (1978) have shown that mechanized sounds have much higher intensities than naturally-occurring desert sounds. The high forces required to operate heavy equipment and drive ORV's through sand and over rocks generate high-intensity sounds concentrated in the lower frequencies. These high-intensity, low-frequency sounds carry the farthest in desert air and are known to penetrate to distances exceeding 4 kilometers (Rennison and Wallace, 1976). Mechanized sounds are, therefore, able to penetrate deep into desert habitats, beyond the specific location of sound sources.

The superior maneuverability of ORV's has enabled their penetrations into vast regions of formerly quiet desert habitats to occur on a regular basis. ORV's, therefore, amplify their acoustical impact on the desert ecosystem by carrying high-intensity sound sources deep into the home ranges of hearing-sensitive animals.

ORV's are not the loudest mechanized sound source in the California Desert, however, they occur more frequently than any comparable high-intensity sound source (Bondello and Brattstrom, 1978). It is the penetrating, far-ranging nature of ORV use and concentrated use of specific fragile habitats that comprise the greatest acoustical threat to desert wildlife. The problem, in effect, is not the abilities of specific sounds to carry into desert regions, but the abilities of specific sound sources to penetrate deep into these reaches.

Sand dune inhabitants (Uma and Dipodomys) are particularly vulnerable to ORV sounds. Accounting for this vulnerability requires a brief review of the unique acoustical characteristics of sand dunes. Dune systems are characterized by intense heat and dryness which serve to rapidly attenuate sound conduction. These habitats also have high sloping barrier dunes on their peripheries, which drop to bowl-shaped depressions within interiors of dune systems. These high dunes act

as acoustical barriers (Federal Highway Administration, 1976) which block the entrance of loud sounds into the interior dunes. Interior dunes, therefore, represent a "shadow zone" wherein sound levels are quite low (Bondello and Brattstrom, 1978) and it is here that many hearing-sensitive animals exist. Interior dunes are also regions that are heavily impacted by frequent, loud incursions of dune buggies. Sound exposures similar to these immediately devastated the hearing acuities of dune residents (Uma and Dipodomys) investigated in this report. Vertebrates of the dunes are simply incapable of absorbing the impact of even the most moderate of ORV sound exposures.

Apparently, the wildlife of sand dune peripheries (Scaphiopus couchi) are also vulnerable to ORV impact. Mayhew (1965) reported isolated populations of S. couchi near Glamis, Imperial County, California. Recent field surveys of S. couchi in California by Dimmitt (1977) reported intact populations of spadefoot toads throughout the regions northwest and northeast of Glamis in areas that are relatively free of ORV impact. However, spadefoot toad populations reported by Mayhew (1965) 2 miles and 7 miles southeast of Glamis, clustered along the Algodones Dunes were not seen. It is this area south of Glamis that has received intense ORV impact in the past ten years. The current status of spadefoot toads within this ORV use area is still unknown. The reliance of S. couchi on acoustical (Bondello and Brattstrom, 1979a) and vibratory (Dimmitt, 1975) stimuli to elicit their emergence from subterranean burrows and their absence from formerly established localities, now intensely used ORV areas, certainly implies that ORV's have had a disruptive influence on these populations of spadefoot toads.

The best available scientific data, therefore, indicates that acoustical impacts of ORV's on the California Desert pose a clear

and present danger to the well-being of desert vertebrates. Each class of vertebrate tested revealed that disturbing or destructive effects resulted from ORV sound exposures less than those which actually and regularly occur in the desert. Animals from quiet protected sand dunes (Uma and Dipodomys) were the most vulnerable and suffered immediate loss of hearing when exposed to these sounds. Recovery was gradual (D. deserti) and took several weeks, during which time the demonstrated auditory abilities of prey animals to detect predator approach dropped below levels requisite for survival (Bondello and Brattstrom, 1979b). Experimental evidence indicates that equivalent (or higher) cumulative doses of ORV sounds will, likewise, damage the hearing abilities of similar animals (Bondello, Huntley, Cohen, and Brattstrom, 1979).

The desert sand dunes represent a critical habitat to the Fringe-Toed Lizards and Desert Kangaroo Rats that live only in these systems. The vital requirements of space, nutrients, shelter, breeding sites, dunes for buffering sounds, sand for grooming, burrow construction, food caching, cover and concealment are provided only on these sand dune systems. Desert sand dunes are, thus, in every respect, critical habitats of these indigenous species of wildlife. It is this critical sand dune habitat that is currently overexploited and threatened by ORV activities. Subsequently, the Fringe-Toed Lizards and Desert Kangaroo Rats that are narrowly restricted to undisturbed sand dune systems are also threatened by ORV intrusions into these regions.

Based upon the best available scientific data we, therefore, recommend that the following measures be taken to protect the unique habitats and wildlife of the California Desert:

- 1) Desert sand dune systems should be designated as "critical habitats" of all species of Fringe-Toed Lizard (Uma) and Desert Kangaroo Rats (Dipodomys deserti).
- 2) All Fringe-Toed Lizards and Desert Kangaroo Rats should be afforded protected status to ensure their survival on undisturbed dune habitats.
- 3) ORV and other disturbing activities should be totally restricted from undisturbed desert sand dune systems and from their peripheries.
- 4) ORV and other disturbing activities should be totally restricted from areas of known Scaphiopus couchi populations.
- 5) Recreational ORV's should be restricted from the wide-ranging use of public lands.
- 6) Public lands designated for ORV use should be regulated to ensure total confinement of ORV impacts to relatively small areas.
- 7) ORV designated areas should be located away from all undisturbed desert habitats, critical habitats, and all ranges of threatened, endangered, or otherwise protected desert species.
- 8) Undisturbed public lands should be restricted from consideration as ORV use areas.
- 9) ORV designated areas should be properly monitored and maintained, at ORV operators' expense, to limit erosive influences on the environment.
- 10) All of the foregoing recommendations should be strictly enforced to ensure the survival and perpetuation of the unique California Desert ecosystem.

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